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U.S. DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA

ADR

9 Attorneys for Plaintiff
10 GOLDEN GATE TECHNOLOGY, INC.

11 **UNITED STATES DISTRICT COURT**

12 **NORTHERN DISTRICT OF CALIFORNIA** *EDL*

13 GOLDEN GATE TECHNOLOGY, INC., a
14 California Corporation

15 Plaintiff,

16 vs.

17 MAGMA DESIGN AUTOMATION, INC., a
18 Delaware Corporation,

19 Defendant

20) Case No.: **CV 11-04862**
21) **COMPLAINT FOR PATENT
22) INFRINGEMENT**

23) **JURY TRIAL DEMANDED**

24)
25)
26)
27)
28)
Complaint for Patent Infringement

Case No.

1 Plaintiff GOLDEN GATE TECHNOLOGY, INC (“GGT”) hereby alleges as follows:

2 **INTRODUCTION**

3 1. This is a patent infringement action wherein GGT alleges that MAGMA DESIGN
 4 AUTOMATION, INC. (“MAGMA”) is, and has been, infringing, contributing to the
 5 infringement of, and/or actively inducing others to infringe claims of U.S. Patent Nos.
 6 7,360,193 (“193 Patent”) and 7,823,112 (“112 Patent”) (collectively “Asserted Patents”).

7 **PARTIES**

8 2. Plaintiff GOLDEN GATE TECHNOLOGY, INC. is a California corporation with
 9 its principal place of business at 1101 S. Winchester Blvd., Suite J-255, San Jose, California
 10 95128.

11 3. On information and belief, and thereon alleged, Defendant MAGMA DESIGN
 12 AUTOMATION, INC. is a Delaware corporation with its principal place of business at 1650
 13 Technology Dr., San Jose, California 95110.

14 **JURISDICTION AND VENUE**

15 4. This Court has subject matter jurisdiction pursuant to 28 U.S.C. §§ 1331 and
 16 1338(a) as this action arises under the patent laws of the United States, 35 U.S.C. § 1, et seq.,
 17 including 35 U.S.C. § 271.

18 5. This Court has personal jurisdiction over MAGMA, who maintains its principal
 19 place of business in this District, has conducted and does conduct business within the State of
 20 California and within this District, and because a substantial part of the events giving rise to
 21 GGT’s claims occurred in this District.

22 6. Venue is proper in this Court pursuant to 28 U.S.C. §§ 1391(b), (c) and/or 1400(b)
 23 because MAGMA is subject to personal jurisdiction in this District, conducts business in this
 24 District, and because a substantial part of the events giving rise to GGT’s claims occurred in
 25 this District.

26 **INTRADISTRICT ASSIGNMENT**

27 7. This is an Intellectual Property Action to be assigned on a district-wide basis
 28 pursuant to Civil Local Rule 3-2(c).

FACTUAL BACKGROUND

8. The field of electronic design automation (“EDA”) pertains to the use of computer software and hardware for the design, analysis and creation of electronics and electronic components, including circuits and integrated circuits.

9. Circuit designers may use EDA software to automatically, or semi-automatically, place and/or configure circuit components and circuits.

10. Circuits often incorporate the use of 1) timing circuits, to ensure that signals are captured at predetermined locations at certain times, and 2) switches, which can interrupt and/or divert signals. As circuits become more complex, accurate and reliable timing and switching are increasingly important in circuit design and function.

11. Circuit designers face multiple challenges in designing circuits to meet the demand for ever smaller sized components and for products with increased functionality and more efficient power consumption. As circuits are made ever smaller and more complex, the size and placement of wires and components for such circuits have an ever increasing impact on the timing and switching that occurs in the circuit. Improper or inefficient component placement and/or wire routing can result in inefficiencies and improper function, such as increased power consumption, inconsistent timing, inefficient function, and even outright inoperability.

12. GGT's innovations in the EDA field are critical for increasing the efficiency of EDA-based circuit design and reducing power consumption in circuits designed using EDA tools. GGT's innovations provide for improvements in the ability to design circuits and integrated circuits by taking into account, among other things, timing, switching, and power utilization when placing circuit components and routing wires in such circuits.

13. On or about April 15, 2008, the United States Patent and Trademark Office (“USPTO”) issued the ‘193 Patent entitled “Method for Circuit Block Placement and Circuit Block Arrangement Based on Switching Activity” to GGT, the assignee of the entire interest. Attached hereto as Exhibit A is a true and correct copy of the ‘193 Patent.

11

1 14. On or about October 26, 2010, the USPTO issued the '112 Patent entitled
2 "Method, Software and System for ensuring Timing Between Clocked Components in a
3 Circuit" to GGT, the assignee of the entire interest. Attached hereto as Exhibit B is a true and
4 correct copy of the '112 Patent.

5 15. On information and belief, and thereon alleged, MAGMA designs, develops,
6 makes, sells and supports EDA software, and provides consulting, training, and other services
7 in support of their products.

8 16. On information and belief, and thereon alleged, MAGMA has made, used, sold,
9 imported and/or offered for sale, and/or continues to make, use, sell, import and/or offer for
10 sale products in the United States consisting of, or including, EDA algorithms, methods and
11 software (collectively "Accused Products") which infringe on the Asserted Patents.

12 17. On information and belief, and thereon alleged, the Accused Products also include
13 MAGMA's Talus® line of software, under titles such as Talus® Design, Talus® Vortex,
14 Talus® Vortex FX, and Talus® Power Pro.

15 18. MAGMA's making, using, selling, offering for sale, and/or importing of the
16 Accused Products in the United States constitutes direct infringement of the Asserted Patents.

17 19. On information and belief, and thereon alleged, MAGMA has sold or offered to
18 sell the Accused Products to third parties who use the Accused Products to design and/or
19 make their own products. Thus, MAGMA is contributing, and has contributed, to the
20 infringement of the Asserted Patents.

21 20. MAGMA has been aware of GGT's patent portfolio, including the Asserted
22 Patents, since at least March 2008.

23 21. GGT is entitled to recover from MAGMA the actual damages it sustained and
24 continues to sustain as a result of MAGMA's wrongful acts alleged herein under 35 U.S.C. §
25 284 in an amount to be proven at trial, together with interest and costs.

26 22. On information and belief, and thereon alleged, MAGMA's infringement of the
27 Asserted Patents is, and has been, willful, deliberate, and in disregard of GGT's patent rights,
28

1 and pursuant to 35 U.S.C. §§ 284 and 285, GGT is therefore entitled to enhanced damages up
 2 to three times the amount of actual damages and attorneys' fees.

3 **FIRST CAUSE OF ACTION**
 4 **Infringement of U.S. Patent No. 7,360,193**
 5 **under 35 U.S.C. § 271, et. seq.**

6 23. The allegations of paragraphs 1-22 are incorporated herein as if fully set forth.
 7 24. MAGMA actively and knowingly has infringed, and is infringing, the '193 patent
 8 with knowledge of GGT's patent rights and without reasonable basis for believing that
 MAGMA's conduct is lawful.

9 25. MAGMA has induced and contributed, and is continuing to induce and contribute,
 10 to the infringement of the '193 patent by purchasers, licensees, and users of the Accused
 11 Products.

12 26. MAGMA's acts of infringement have been and continue to be willful, deliberate,
 13 and in reckless disregard of GGT's patent rights.

14 27. MAGMA has injured GGT and is thus liable to GGT for infringement of the '193
 15 patent pursuant to 35 U.S.C. § 271.

16 **SECOND CAUSE OF ACTION**
 17 **Infringement of U.S. Patent No. 7,823,112**
 18 **under 35 U.S.C. § 271, et. seq.**

19 28. The allegations of paragraphs 1-22 are incorporated herein as if fully set forth.
 20 29. MAGMA actively and knowingly has infringed and is infringing the '112 patent
 with knowledge of GGT's patent rights and without reasonable basis for believing that
 MAGMA's conduct is lawful.

21 30. MAGMA has induced and contributed, and is continuing to induce and contribute,
 22 to the infringement of the '112 patent by purchasers, licensees, and users of the Accused
 23 Products.

24 31. MAGMA's acts of infringement have been and continue to be willful, deliberate,
 25 and in reckless disregard of GGT's patent rights.

26 32. MAGMA has injured GGT and is thus liable to GGT for infringement of the '112
 27 patent pursuant to 35 U.S.C. § 271.

PRAYER FOR RELIEF

WHEREFORE, PLAINTIFF prays for the following relief from this Court:

- a) An adjudication that MAGMA has infringed and continues to infringe the Asserted Patents as alleged above;
- b) An accounting of all damages sustained by GGT as a result of MAGMA's acts of infringement of the Asserted Patents;
- c) An award to GGT of actual damages adequate to compensate GGT for MAGMA's acts of patent infringement, together with prejudgment and post judgment interest;
- d) An award of GGT's attorneys' fees and costs pursuant to 35 U.S.C. § 285;
- e) Awarding such other and further relief as this Court may deem just and proper.

Date: September 27, 2011

Respectfully Submitted,
THE LAW OFFICES OF ANDREW D.
FORTNEY, Ph.D., P.C.

By: Bradley, Levang
ANDREW D. FORTNEY
SHERRIE M. FLYNN
BRADLEY J. LEVANG
Attorneys for Plaintiff
GOLDEN GATE TECHNOLOGY, INC.

DEMAND FOR A JURY TRIAL

GGT hereby demands a jury trial for all issues so triable.

Date: September 27, 2011

Respectfully Submitted,
THE LAW OFFICES OF ANDREW D.
FORTNEY, Ph.D., P.C.

By: Bradley Levang
ANDREW D. FORTNEY
SHERRIE M. FLYNN
BRADLEY J. LEVANG
Attorneys for Plaintiff
GOLDEN GATE TECHNOLOGY, INC.

EXHIBIT A



US007360193B1

(12) **United States Patent**
Burstein et al.

(10) **Patent No.:** US 7,360,193 B1
(45) **Date of Patent:** Apr. 15, 2008

(54) **METHOD FOR CIRCUIT BLOCK PLACEMENT AND CIRCUIT BLOCK ARRANGEMENT BASED ON SWITCHING ACTIVITY**

6,662,348 B1 * 12/2003 Naylor et al. 716/9
6,725,438 B2 4/2004 Van Ginneken

(Continued)

(75) Inventors: **Michael Burstein**, Cupertino, CA (US);
Mikhail Komorov, Moscow (RU);
Georgy Sergeev, Moscow (RU)

(73) Assignee: **Golden Gate Technology, Inc.**, San Jose, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 371 days.

(21) Appl. No.: 10/946,925

(22) Filed: Sep. 21, 2004

(51) **Int. Cl.**

G06F 17/50 (2006.01)
G06F 9/45 (2006.01)
G06F 9/455 (2006.01)

(52) U.S. Cl. 716/10; 716/9; 716/6

(58) **Field of Classification Search** 716/9-10,

716/6

See application file for complete search history.

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Primary Examiner—Paul Dinh

Assistant Examiner—Suresh Memula

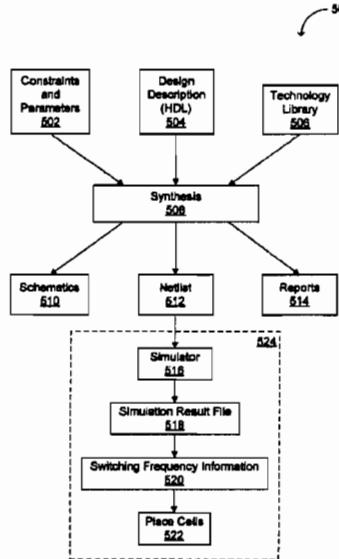
(74) **Attorney, Agent, or Firm**—Andrew D. Fortney; Alec B. Plumb

(57)

ABSTRACT

A method, algorithm, software, architecture and/or system for placing circuit blocks and/or routing wires in a circuit design is disclosed. In one embodiment, a method of placing can include: (i) determining a first signal path between first and second circuit blocks and determining a second signal path between first and third circuit blocks; and (iii) placing the first circuit block relative to the second and third circuit blocks in a position related to a switching activity of the first and second signal paths. The circuit blocks can include standard cells configured to implement a logic function, other components, or integrated circuits, for example. The switching activity can include a switching frequency determination based on simulation results of the first and second signal paths between the circuit blocks. Embodiments of the present invention can advantageously reduce power consumption as well as supply noise by optimally placing circuit blocks in an automated place-and-route flow. Further, signal integrity problems due to non-optimal circuit block or component placement can be minimized.

25 Claims, 4 Drawing Sheets



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U.S. Patent

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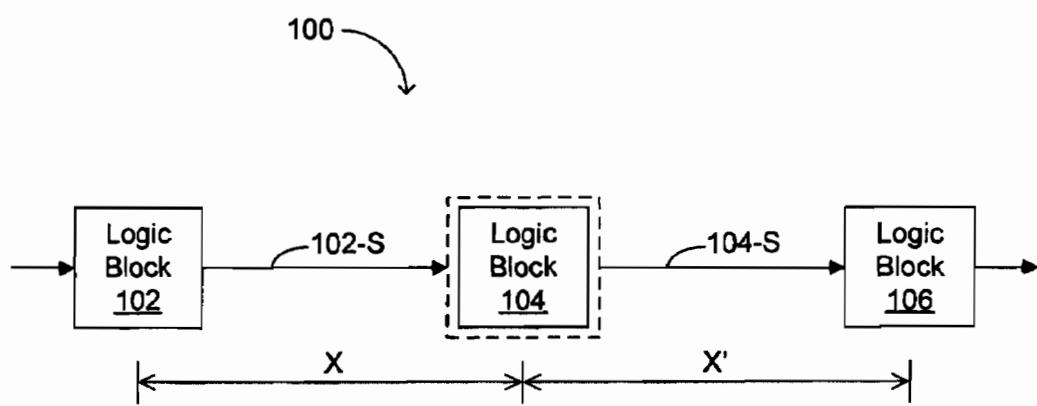


FIG. 1 (conventional)

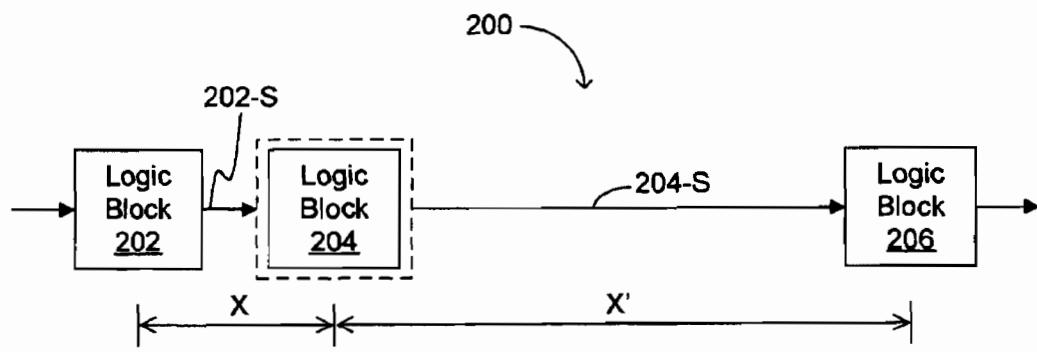


FIG. 2

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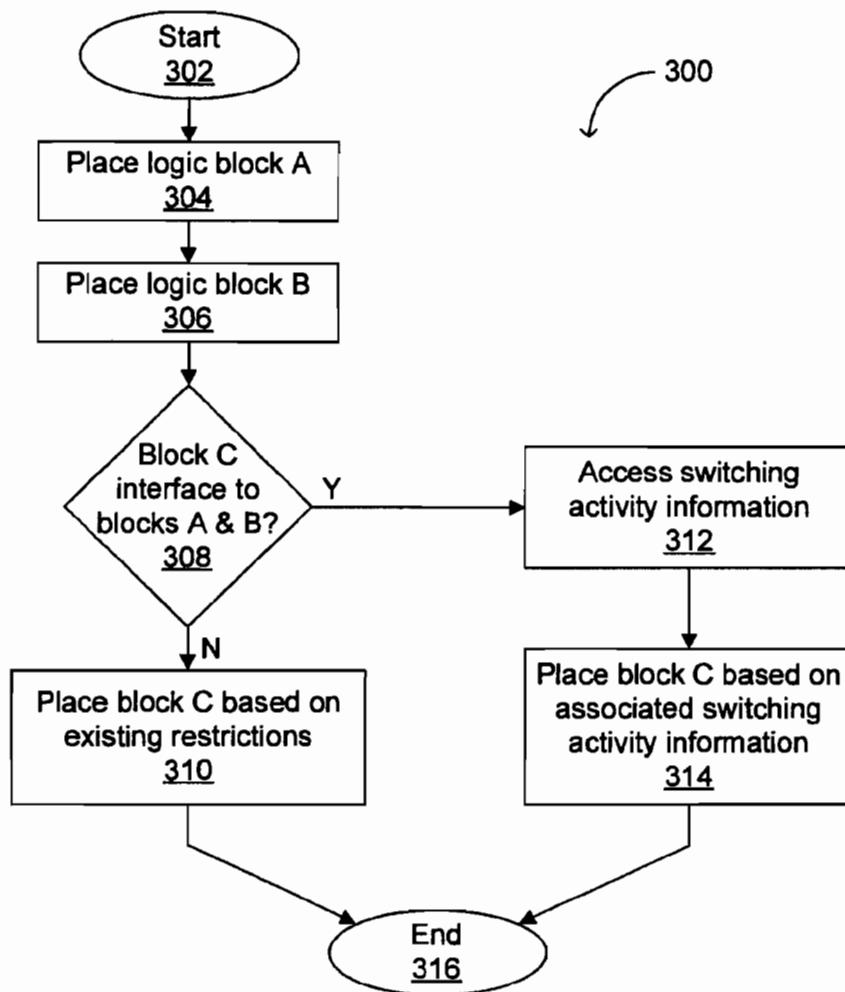


FIG. 3

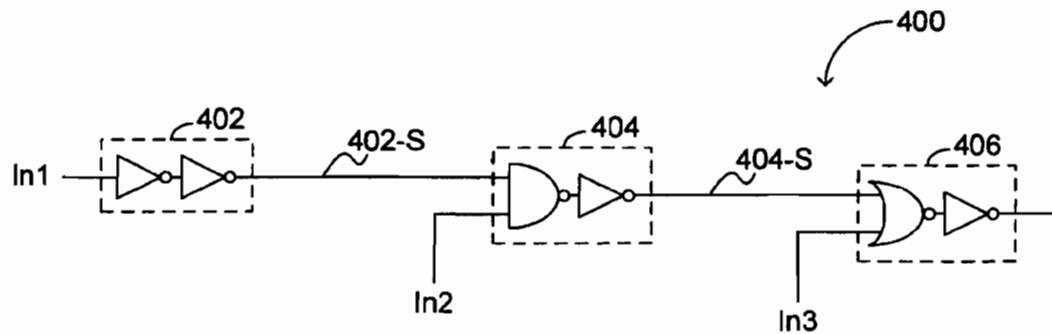


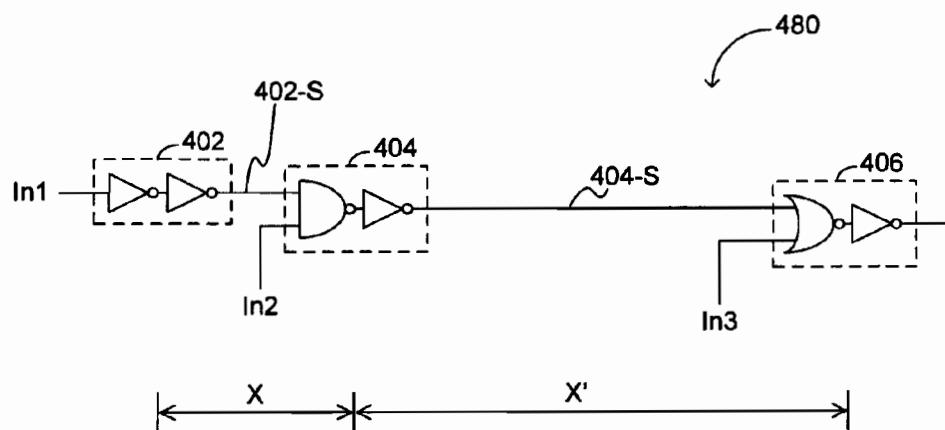
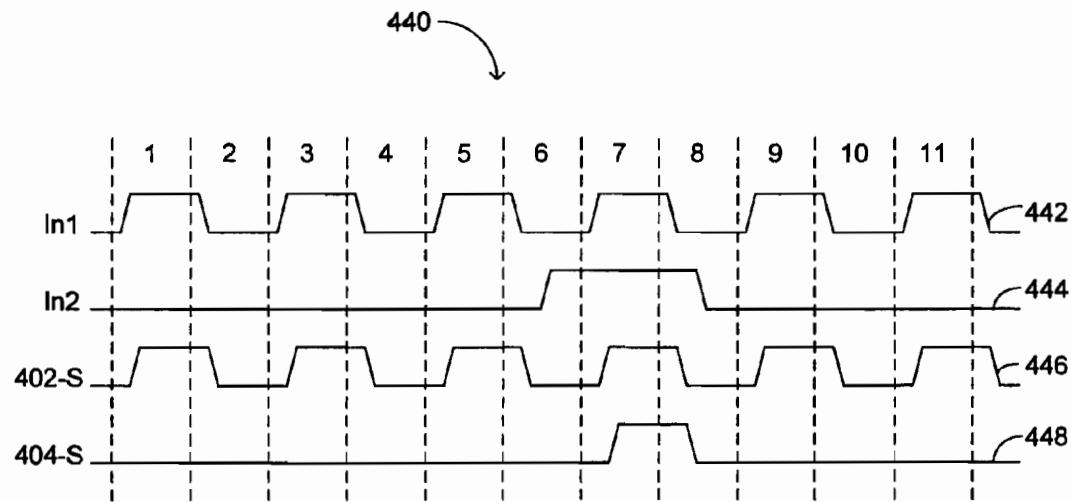
FIG. 4A

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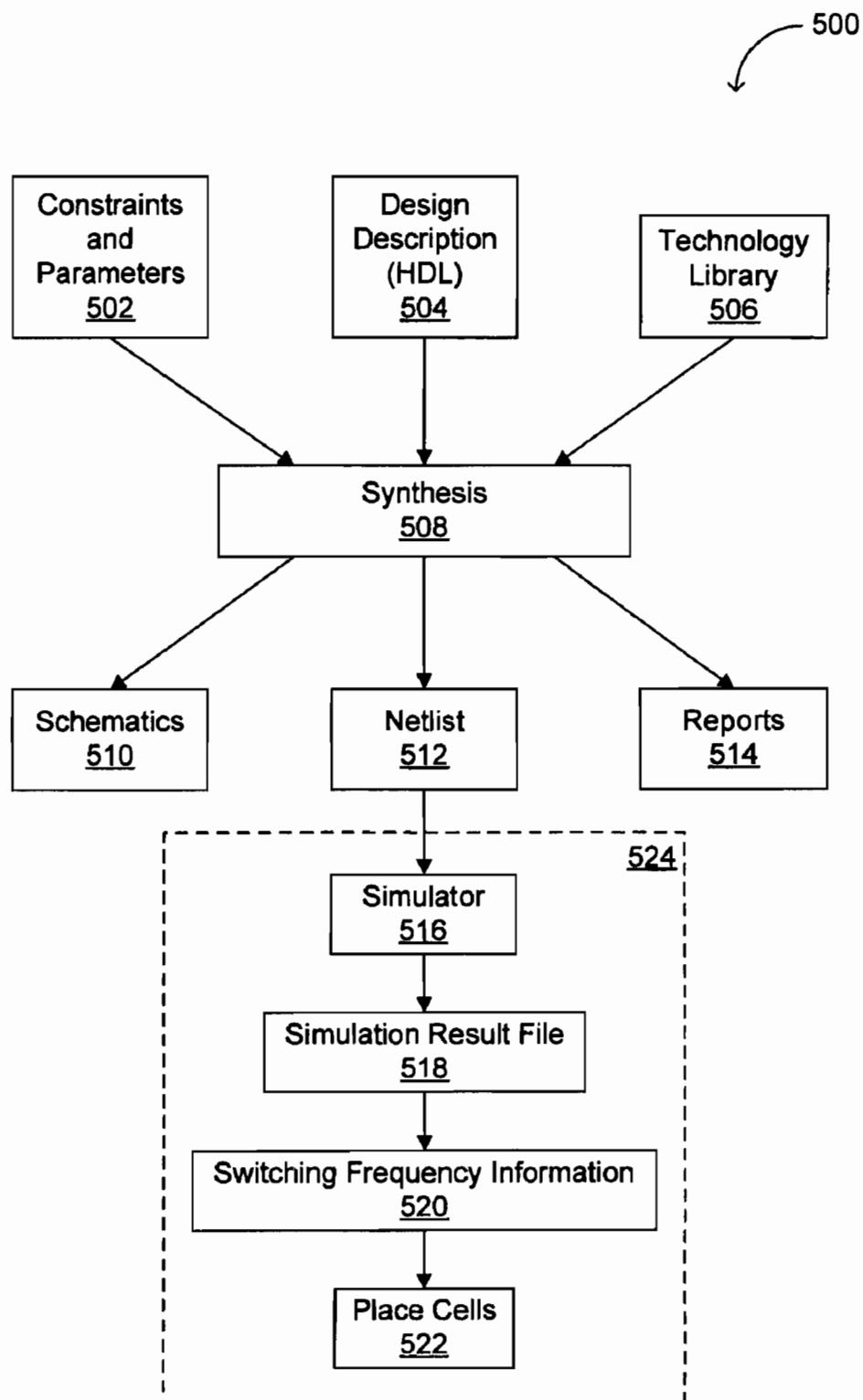


FIG. 5

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**METHOD FOR CIRCUIT BLOCK
PLACEMENT AND CIRCUIT BLOCK
ARRANGEMENT BASED ON SWITCHING
ACTIVITY**

FIELD OF THE INVENTION

The present invention generally relates to the field of circuit design, particularly integrated circuit (IC) design. More specifically, embodiments of the present invention pertain to methods, algorithms, software, systems and architectures for reducing power consumption and improving signal integrity in the design of an IC.

DISCUSSION OF THE BACKGROUND

In typical circuit design, circuit components are arranged to optimize space and/or circuit performance. Such arrangements can include the "layout" or pattern definition of each of the layers used in a semiconductor manufacturing process. For example, such layout can include metal interconnect layers that are converted to masks or reticles for use in a wafer fabrication facility that manufactures ICs (i.e., "chips").

While some circuits are designed using "custom" layout, others are designed using a partially or fully automated design flow. Application-Specific Integrated Circuit (ASIC) designs, as well as other functional blocks within a larger chip, such as System-On-Chip (SOC) designs, may employ custom and/or ASIC type flows on the same chip. In any event, typical ASIC flows use "place-and-route" tools for placing logic or circuit "blocks" and then "routing" or connecting the interface signals between the blocks.

Referring now to FIG. 1, a box diagram of a circuit block placement resulting from the use of conventional placement tools is shown and indicated by the general reference character 100. Logic Block 102 can interface to Logic Block 104 via signal 102-S. Similarly, Logic Block 104 can interface to Logic Block 106 via signal 104-S. In this example, Logic Block 102 and Logic Block 106 are initially placed by the conventional placement tool. Then, Logic Block 104 is placed. Because of interfaces to both Logic Block 102 and Logic Block 106, the conventional placement tool will place Logic Block 104 either arbitrarily or substantially in the middle between Logic Blocks 102 and 106 (i.e., distance X is about equal to distance X'). One conventional approach, for example, uses a summation of the squares in the interface signal paths to determine the middle location for the placement of Logic Block 104.

However, such conventional approaches to automated block placement are not optimized for power consumption or signal integrity concerns. Limitations of such conventional approaches result from the fact that the switching frequency of signal 102-S is not likely to be the same as that of signal 104-S. Accordingly, the placement of Logic Block 104 substantially in the middle between Logic Blocks 102 and 106 does not necessarily minimize the power being drawn or the supply noise in the situation where the switching frequencies are not equal.

Given the increasing demands on circuit designers to create chips of increasing density, decreasing wire and transistor widths, and decreasing power supply and power consumption, it is difficult to ensure optimal circuit block placement, particularly in an automated placement flow. Increasing the complexity, flexibility and/or functionality of the circuitry on a chip exacerbates these challenges. Thus, what is needed is a tool with which integrated circuit

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designers can automatically optimize circuit placement so as to reduce power consumption and increase signal integrity.

SUMMARY OF THE INVENTION

Embodiments of the present invention relate to methods, algorithms, software, architectures and/or systems for placing circuit blocks and/or routing wires in a circuit design.

In one embodiment, a method of placing can include: (i) determining a switching activity for (1) a first signal path between a first circuit block and a second circuit block and (2) a second signal path between the first circuit block and a third circuit block; and (ii) placing the first circuit block relative to the second and third circuit blocks in a position related to a switching activity of the first and second signal paths. The circuit blocks can include standard cells configured to implement a logic function, other components, or integrated circuits, for example. The switching activity can include a switching frequency determination based on simulation results of the first and second signal paths between the circuit blocks.

Embodiments of the present invention can advantageously reduce power consumption as well as supply noise by optimally placing circuit blocks in an automated place-and-route flow. Further, signal integrity problems due to non-optimal circuit block or component placement can be minimized relative to placing the circuit blocks by a summation of the squares (or "middle placement") technique. Embodiments of the invention are suitable for the automated placement of circuit blocks within an integrated circuit (IC) and/or placements of ICs or components on a board, such as a printed circuit board (PCB).

These and other advantages of the present invention will become readily apparent from the detailed description of preferred embodiments below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a box diagram of a circuit block placement resulting from the use of conventional placement tools.

FIG. 2 is a box diagram of circuit block placement resulting from the use of an embodiment of the present invention.

FIG. 3 is a flow diagram showing a circuit block placement method according to an embodiment of the present invention.

FIG. 4A is schematic diagram showing an exemplary circuit that may be used in embodiments of the present invention.

FIG. 4B is an example timing diagram for the circuit of FIG. 4A.

FIG. 4C is a schematic diagram showing a relative placement of circuit block portions of the circuit of FIG. 4A resulting from the use of embodiments of the present invention.

FIG. 5 is a box diagram showing a synthesis flow adapted for use with embodiments of the present invention.

**DETAILED DESCRIPTION OF THE
PREFERRED EMBODIMENTS**

Reference will now be made in detail to the preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. While the invention will be described in conjunction with the preferred embodiments, it will be understood that they are not intended to limit the invention to these embodiments. On the contrary,

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the invention is intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope of the invention as defined by the appended claims. Furthermore, in the following detailed description of the present invention, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be readily apparent to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components, and circuits have not been described in detail so as not to unnecessarily obscure aspects of the present invention.

Some portions of the detailed descriptions which follow are presented in terms of processes, procedures, logic blocks, functional blocks, processing, and other symbolic representations of operations on code, data bits, data streams or waveforms within a computer, processor, controller and/or memory. These descriptions and representations are generally used by those skilled in the data processing arts to effectively convey the substance of their work to others skilled in the art. A process, procedure, logic block, function, process, etc., is herein, and is generally, considered to be a self-consistent sequence of steps or instructions leading to a desired and/or expected result. The steps generally include physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical, magnetic, optical, or quantum signals capable of being stored, transferred, combined, compared, and otherwise manipulated in a computer or data processing system. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, waves, waveforms, streams, values, elements, symbols, characters, terms, numbers, or the like, and to their representations in computer programs or software as code (which may be object code, source code or binary code).

It should be borne in mind, however, that all of these and similar terms are associated with the appropriate physical quantities and/or signals, and are merely convenient labels applied to these quantities and/or signals. Unless specifically stated otherwise and/or as is apparent from the following discussions, it is appreciated that throughout the present application, discussions utilizing terms such as "processing," "operating," "computing," "calculating," "determining," "manipulating," "transforming," "displaying" or the like, refer to the action and processes of a computer or data processing system, or similar processing device (e.g., an electrical, optical, or quantum computing or processing device), that manipulates and transforms data represented as physical (e.g., electronic) quantities. The terms refer to actions and processes of the processing devices that manipulate or transform physical quantities within the component(s) of a system or architecture (e.g., registers, memories, other such information storage, transmission or display devices, etc.) into other data similarly represented as physical quantities within other components of the same or a different system or architecture.

Furthermore, in the context of this application, the terms "net list" (or "netlist") and "hardware description" may be used interchangeably to refer to a circuit design represented in an appropriate language, such as VERILOG simulation language, Hardware Description Language (HDL) or VERILOG HDL (VHDL; VERILOG is a registered trademark of Gateway Design Automation Corporation for computer aided electrical engineering programs). Similarly, the terms "wire," "wiring," "line," "signal," "conductor" and "bus" refer to any known structure, construction, arrangement, technique, method and/or process for physically transferring

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a signal from one point in a circuit to another. Also, unless indicated otherwise from the context of its use herein, the terms "known," "fixed," "given," "certain" and "predetermined" generally refer to a value, quantity, parameter, constraint, condition, state, process, procedure, method, practice, or combination thereof that is, in theory, variable, but is typically set in advance and not varied thereafter when in use.

Similarly, for convenience and simplicity, the terms "clock," "time," "timing," "rate," "period" and "frequency" are, in general, interchangeable and may be used interchangeably herein, but are generally given their art-recognized meanings. Also, for convenience and simplicity, the terms "data," "data stream," "waveform" and "information" may be used interchangeably, as may (a) the terms "flip-flop," "latch" and "register," and (b) the terms "connected to," "coupled with," "coupled to," and "in communication with," but these terms are generally given their art-recognized meanings herein.

The present invention concerns a method and/or algorithm (e.g., a computer-readable set of instructions) for placing circuit blocks, and can include: (i) determining switching activities for a first signal path between first and second circuit blocks and a second signal path between first and third circuit blocks; and (ii) placing the first circuit block relative to the second and third circuit blocks in a position related to a switching activity of the first and second signal paths. The circuit blocks can include standard cells configured to implement a logic function, other components, or integrated circuits, for example. The switching activity can include a switching frequency determination based on simulation results of the first and second signal path between the circuit blocks.

In a further aspect of the invention, the software relates to a medium or waveform containing a computer-readable set of instructions, where the instructions can include: (i) determining a first weighting of a first signal path between first and second circuit blocks and a second weighting of a second signal path between first and third circuit blocks; and (ii) placing the first circuit block relative to the second and third circuit blocks in a position related to the first and second weightings. The weightings can each include a switching activity factor for each of the signal paths.

In another aspect of the invention, a method and/or algorithm of arranging can include: (i) placing first and second circuit blocks; (ii) determining whether a third circuit block interfaces with the first and second circuit blocks; and (iii) if the third circuit block interfaces with the first and second circuit blocks, then: accessing switching activity information for signal paths connecting the third circuit block to the first and second blocks; and placing the third circuit block relative to the first and second circuit blocks in a position related to the switching activity information for the signal paths.

In another aspect of the invention, an arrangement of circuit blocks can include: (i) a first circuit block in a first position and coupled to a third circuit block via a first signal path; (ii) a second circuit block in a second position and coupled to the third circuit block via a second signal path; and (iii) the third circuit block in a third position, the third position being based at least in part on the relative switching activities of the first and second signal paths.

Embodiments of the present invention can advantageously reduce power consumption as well as supply noise by optimally placing circuit blocks in an automated place-and-route flow. Further, signal integrity problems due to non-optimal circuit block or component placement can be

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minimized. Embodiments of the invention are suitable for the automated placement of circuit blocks within an integrated circuit (IC) and/or placements of ICs or components on a board, such as a printed circuit board (PCB).

The invention further relates to hardware and/or software implementations of the present architecture, method and system. The invention, in its various aspects, will be explained in greater detail below with regard to exemplary embodiments.

Referring now to FIG. 2, a box diagram of circuit block placement resulting from the use of an embodiment of the present invention is shown and indicated by the general reference character 200. Logic Block 202 can interface to Logic Block 204 via signal or "signal path" 202-S. Logic Block 204 can also interface to Logic Block 206 via signal 204-S. In this example, the switching activity of signal 202-S may be higher than the switching activity of signal 204-S. For example, signal 202-S may switch state (i.e., from a "high" or "1" to a "low" or "0" or vice versa) ten times in a given time period. However, in that same given time period, signal 204-S may only switch state one time. Because the current drawn from the power supply is proportional to the capacitive load being driven, it is typically desirable to minimize capacitive loads, particularly on signals that may switch states often (i.e., high "switching activity" signals). According to embodiments of the present invention, the switching activity of signal 202-S can be determined and compared with that of signal 204-S so as to identify a relative position for the placement of Logic Block 204. Thus, in this example, distance X is less than distance X', so as to reduce the capacitance of signal path 202-S, as indicated. Moreover, Logic Block 204 may be placed substantially adjacent to or otherwise in proximity with Logic Block 202.

Of course, as one skilled in the art will recognize, embodiments of the present invention are also applicable to analog, ternary, or other non-digital circuits. As one example, "small-signal" circuits, either alone or embedded within a larger chip or PCB may employ embodiments of the present invention. In general, embodiments of the present invention can be used in the placement of circuit blocks having interface signals that change states. Further, such state changes suitable for a "switching activity" determination may be of any type (e.g., analog, digital, etc.) recognizable by the interfacing or surrounding circuitry.

In this fashion, a circuit or logic block can be placed in a relative position based on the switching activity of associated signals. Accordingly, the capacitance of signal paths for certain higher switching activity signals can typically be reduced. Thus, the overall power consumption of a circuit can effectively be reduced by the use of embodiments of the present invention. In one implementation, a power reduction of about 15-20% was realized. Further, signal integrity problems can also be minimized due to increased power supply stability.

Referring now to FIG. 3, a flow diagram showing a circuit block placement method according to an embodiment of the present invention is indicated by the general reference character 300. The flow can begin in Start 302 and a logic block "A" can be placed (304). Logic block "B" can be placed in 306. In this example, logic blocks A and B may be placed using conventional placement restrictions, such as placement within designated areas or regions on a chip floorplan. Of course, while the placing of logic block B (306) is shown in FIG. 3 as a sequential operation to the placing of logic block A (304), one skilled in the art will recognize that no sequential dependency is implied. In fact,

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logic block B could be placed prior to logic block A or logic blocks A and B could be placed simultaneously. Next, it can be determined whether the next block to be placed (logic block "C") interfaces to the already-placed logic blocks A and B (308). Such a determination of an "interface" between logic blocks can be made by reference to a "netlist" file. Netlist files can be generated, for example, by a synthesizer based on a Hardware Description Language (HDL) representation of the logic functions of a circuit (which generally includes logic blocks A, B and C), as will be discussed in more detail below with reference to FIG. 5.

In FIG. 3, if logic block C does not interface to logic blocks A and B, then block C can be placed based on existing or conventional restrictions (310) and the flow can complete in End 316. For example, if block C interfaces to block A, but not block B, then logic block C may be placed in the region of block A, but not necessarily between blocks A and B. Similarly, if block C interfaces to block B, but not block A, then logic block C may be placed in the region of block B, but not necessarily between blocks A and B. Such placements may of course be subject to overriding restrictions, such as placement within designated areas or regions on a chip floorplan.

If it is determined that logic block C does interface to already-placed logic blocks A and B, then associated switching activity information can be accessed (312). Such switching activity information can include a switching frequency based on an event-driven simulation, such as a VERILOG simulation. Further, the switching activity information can include a user-controlled factor that may be multiplied with a switching activity (i.e., switching frequency) factor. Next, logic block C can be placed in a relative position based on associated switch activity information (314) and the flow can complete in End 316. The placement of block C in a relative position between, or in proximity with at least one of, blocks A and B can be determined by formula (1), as follows:

$$\text{weight(net)} = \text{length(net)} + P \cdot S_w(\text{net}) \quad (1)$$

The result term "weight(net)" can be a weighting so as to designate the relative position of the new block placement. The term "length(net)" can be an initial length of a signal path, such as may be determined by conventional placement approaches. Alternatively, "length(net)" can represent a current or a projected length of a signal path. The term "P" in the above formula may be the user-controlled factor. The user-controlled factor can be a representation of the importance or priority of a particular signal path relative to other signal paths. For example, a clock signal may have a high priority designation by a user. Further, the term "S_w(net)" can be a switching frequency or switching activity term, for example. As discussed above, this term can be determined by way of simulation of a netlist representation of the overall circuit, for example.

The weighting ("weight(net)") can be used to determine the relative position of a new block placement with respect to existing block placements, such as Logic Block 204 relative to Logic Blocks 202 and 206, as discussed above with reference to FIG. 2. Accordingly, distance X versus distance X' can be determined by accessing the weighting for "nets" or signal paths 202-S and 204-S, for example. In this fashion, a circuit block can be placed in a relative position based on the switching activity of associated signals. Further, the placement can further be dependent on a user-controlled factor as well as an initial and/or projected signal path length.

Referring now to FIG. 4A, a schematic diagram showing an exemplary circuit that may be used in embodiments of the present invention is indicated by the general reference character 400. This example shows a simple circuit structure using standard cells or gates to implement logic or other functions that is suitable for IC design. Such logic functions could include AND/NAND, OR/NOR, XOR/XNOR, INV, or flip-flops, as just a few examples. In practice, any circuit can be designed and treated as a "standard cell" for automatic placement and routing in a larger design. More commonly, a set of standard cells are provided and characterized for each design technology and are utilized in an "off-the-shelf" manner in a typical ASIC design flow.

In the example of FIG. 4A, standard cell 402 can be a buffer stage receiving input In1 and outputting signal 402-S. Standard cell 404 can be an "AND" function having a NAND-gate followed by an inverter. Standard cell 404 can receive signal 402-S and input In2 and can output signal 404-S. Standard cell 406 can be an "OR" function having a NOR-gate followed by an inverter. Standard cell 406 can receive signal 404-S and input In3. Particularly if standard cells 402 and 406 are placed first, embodiments of the present invention can be used to determine a relative placement of standard cell 404. Consistent with such embodiments, a simulation of circuit 400 may be done to determine the switching activity of signals 402-S and 404-S.

Referring now to FIG. 4B, an example timing diagram for the circuit of FIG. 4A is shown and indicated by the general reference character 440. Such a timing diagram can be a waveform representation of a VERILOG simulation result, such as a Value Change Data (VCD) file, for example. Input In1 (waveform 442) can be an oscillating signal, such as a clock, and may go high (i.e., transition from "0" to "1") in odd cycles and go low (i.e., transition from "1" to "0") in even cycles. Input In2, which may be a clock enable signal, for example, can go high in cycle 6 and go low in cycle 8, as shown by waveform 444. Signal 402-S (waveform 446) can be a simple delay of In1 because signal 402-S is the output of buffer stage 402. Signal 404-S can go high in cycle 7 and go low in cycle 8 to reflect the "AND" function of standard cell 404. Thus, over the time period of 11 cycles shown in FIG. 4B, the switching activity of signal 402-S is six times the switching activity of signal 404-S (i.e., six full switching cycles for 402-S versus only one switching cycle for 404-S).

The switching activity of various signals in a circuit, where that circuit has been simulated, can also be determined using a commercially available or custom software tool. For example, if the circuit simulation is done using VERILOG simulation language, a VCD file can be created as an output file. A switching activity interface (SAIF) can be used to determine the switching activity of each signal or "net" in the circuit. An example of a free utility for conversion of a VCD output to SAIF is the "vcv2saif" script, which is available from Synopsys, Inc., of Mountain View, Calif. (www.synopsys.com; in particular, see www.synopsys.com/partners/tapin/saif.html).

Referring now to FIG. 4C, a schematic diagram showing a relative placement of circuit block portions of the circuit of FIG. 4A resulting from the use of embodiments of the present invention is indicated by the general reference character 480. Based on the switching activity of signals 402-S and 404-S in the above example, standard cell 404 can be placed relatively close to standard cell 402. Thus, distance X can be substantially less than distance X' and the capacitance of signal path 402-S can accordingly be less than the capacitance of signal path 404-S. In this fashion,

power consumption due to driving the relatively high switching frequency signal 402-S can be minimized. Further, the signal integrity of all signals affected by localized power supply noise in the region of standard cell 402 can be improved because such noise can be minimized according to embodiments of the present invention.

While the exemplary circuit block arrangements discussed above generally show the placement of a third circuit block where two other circuit blocks interfacing to the third block have already been placed, these illustrations should not be considered limiting. As one skilled in the art will recognize, three or more previously-placed circuit blocks may have signals that interface to a new block to be placed and embodiments of the present invention are equally adaptable to such applications. In one embodiment, such a new block may be placed in accordance with a two-dimensional average relative position based on associated signal switching activities. In any event, in accordance with embodiments of the present invention, the new block may be placed relative to or in proximity with previously-placed circuit blocks in relation to the switching activity of the associated interface signals.

Referring now to FIG. 5, a box diagram showing a synthesis flow adapted for use with embodiments of the present invention is indicated by the general reference character 500. Box 524 shows elements adapted for use in accordance with embodiments of the present invention. The remaining boxes in FIG. 5 represent a conventional synthesis flow. Inputs to Synthesis 508 typically include Constraints and Parameters 502, Design Description (HDL) 504, and Technology Library 506. Constraints and Parameters 502 may include physical expectations of the design, such as the circuit operating speed and/or the circuit layout area. Design Description (HDL) 504 can be a VERILOG HDL (VHDL) description of the logic operation(s) for synthesis. Technology Library 506 may contain a functional description as well as other information, such as may be related to the area and speed of all standard cells in a given process technology. For example, Technology Library 506 may be specific to a technology generation (e.g., 0.18 micron technology), a company (e.g., TSMC), and a process type (e.g., CMOS; triple-level metal; fast/normal/slow lot variation).

Outputs from Synthesis 508 may include Schematics 510, Netlist 512, and Reports 514. Schematics 510 can be schematic representations of the synthesized functions of Design Description (HDL) 504. Netlist 512 can be a text file description of a physical connection of components, such as standard cells, and can include a description of the various circuit blocks in the design and signal paths between the circuit blocks. Reports 514 can include speed and area data associated with results of Synthesis 508.

As discussed above, a netlist representation (e.g., Netlist 512) may be used for simulation to determine the switching activity of various signals. Accordingly, Simulator 516 can receive Netlist 512 and provide Simulation Result File 518. For example, Simulator 516 can be a VERILOG simulator and Simulation Result File 518 can be a VCD file. Simulation Result File 518 can be used to determine Switching Frequency Information 520. As discussed above, this can be accomplished by the use of a "vcv2saif" utility, for example. Finally, Place Cells 522 can receive Switching Frequency Information 520 so as to make placements based on the switching activity of associated signals.

In this fashion, a conventional ASIC type design flow including synthesis can be adapted for placement of standard cells in accordance with embodiments of the present invention. Alternatively, embodiments of the present invention

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may be used in other design flows whereby a switching activity of signals can be determined via simulation or other means.

Further examples of suitable systems, tools and/or methods in which the present invention is generally applicable include those described in, e.g., U.S. Pat. Nos. 6,080,201 and 5,798,936, the relevant portions of which are each incorporated herein by reference, and those commercially available from place-and-route software vendors such as Cadence Design Systems (e.g., the SILICON ENSEMBLE™, SILICON ENSEMBLE-PKSTM, FIRST ENCOUNTER™, and NANO ENCOUNTER™ tools), Silicon Valley Research, Inc. (e.g., the QIC/APRTM, GARDSTM, SC™ and FLOORPLACER™ tools), Synopsys (e.g., the CHIP ARCHITECT™, DESIGN COMPILER™, and FLOORPLAN COMPILER™ tools) and Mentor Graphics (e.g., the AUTOCELLSTM tool).

Thus, embodiments of the present invention can advantageously reduce power consumption as well as supply noise by optimally placing circuit blocks in an automated place-and-route flow. Further, signal integrity problems due to non-optimal circuit block or component placement can be minimized. Embodiments of the invention are suitable for the automated placement of circuit blocks within an IC and/or placements of ICs or components on a board, such as a printed circuit board (PCB).

The foregoing descriptions of specific embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto and their equivalents.

What is claimed is:

1. A method of placing, comprising the steps of:
 - a) determining a first signal path length and a first switching activity for a first signal path between a first circuit block and a second circuit block and a second signal path length and a second switching activity for a second signal path between said first circuit block and a third circuit block;
 - b) determining a first weighting by multiplying said first switching activity by a first user-controlled factor to form a first result and adding said first result to said first signal path length and a second weighting by multiplying said second switching activity by a second user-controlled factor to form a second result and adding said second result to said first signal path length;
 - c) placing said second and third circuit blocks prior to placing said first circuit block; and
 - d) placing said first circuit block relative to said second and third circuit blocks in a position related to said first weighting and said second weighting.
2. The method of claim 1, wherein the step of determining said first weighting and said second weighting occurs prior to the step of placing said first circuit block.
3. The method of claim 1, further including the step of determining said first and second signal paths.
4. The method of claim 3, wherein the step of determining said first and second signal paths includes matching said first

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and second signal paths to a corresponding two of a plurality of nets in a netlist describing said first, second and third circuit blocks.

5. The method of claim 4, wherein the step of determining said switching activity includes simulating using said netlist.
6. The method of claim 5, wherein said simulating includes an event-based logic simulation.
7. The method of claim 6, wherein said event-based logic simulation includes a VERILOG simulation.
- 10 8. The method of claim 5, wherein the step of determining said switching activity further includes converting an output file from the simulating step to a switching activity file.
9. The method of claim 8, wherein said switching activity file includes a frequency of switching for each signal path over a predetermined time period.
- 10 10. The method of claim 9, wherein the step of placing includes placing said first circuit block closer to said second circuit block if the frequency of switching for said first signal path is greater than the frequency of switching for said second signal path.
11. The method of claim 1, wherein each of the circuit blocks includes a standard cell configured to implement a logic or timing function.
12. The method of claim 11, further including the step of accessing a technology library having a characterization of said standard cell.
13. The method of claim 1, wherein said position is automatically determined by said weighting.
14. The method of claim 1, further including the step of 30 synthesizing a circuit implementation in response to a hardware description.
15. The method of claim 1, wherein each of the circuit blocks includes an integrated circuit or component.
16. The method of claim 1, wherein determining said 35 switching activity for said first signal path comprises determining a frequency of state changes in a signal on said first signal path and determining said switching activity for said second signal path comprises determining a frequency of state changes in a signal on said second signal path.
17. A computer readable medium comprising a computer executable set of instructions adapted to perform the steps of:
 - 40 a) determining a first signal path length and a first switching activity factor of a first signal path between first and second circuit blocks and a second signal path length and a second switching activity factor of a second signal path between first and third circuit blocks;
 - b) determining a first weighting by multiplying said first switching activity factor by a first user-controlled factor to form a first result and adding said first result to said first signal path length and a second weighting by multiplying said second switching activity factor by a second user-controlled factor to form a second result and adding said second result to said first signal path length; and
 - c) placing said first circuit block relative to said second and third circuit blocks in a position related to said first weighting and said second weighting.
18. The medium of claim 17, wherein the step of determining said first and second signal paths occurs prior to the step of placing.
19. The medium of claim 18, wherein the step of determining said first and second signal paths includes matching said first and second signal paths to a corresponding two of a plurality of nets in a netlist describing said first, second and third circuit blocks.

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20. The medium of claim 19, wherein the step of determining said first and second switching activity factors includes simulating using said netlist.

21. The medium of claim 17, wherein each of the circuit blocks includes a standard cell configured to implement a logic function.

22. The medium of claim 17, further including at least one instruction for synthesizing a circuit implementation in response to a hardware description.

23. The medium of claim 17, wherein each of the circuit blocks includes an integrated circuit or component.

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24. A computer system comprising the medium of claim 17, configured to execute said instructions.

25. The method of claim 17, wherein determining said switching activity for said first signal path comprises determining a frequency of state changes in a signal on said first signal path and determining said switching activity for said second signal path comprises determining a frequency of state changes in a signal on said second signal path.

* * * * *

EXHIBIT B



US007823112B1

(12) **United States Patent**
Makarov et al.

(10) **Patent No.:** **US 7,823,112 B1**
(45) **Date of Patent:** **Oct. 26, 2010**

(54) **METHOD, SOFTWARE AND SYSTEM FOR ENSURING TIMING BETWEEN CLOCKED COMPONENTS IN A CIRCUIT**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 422 days.

(21) Appl. No.: **10/449,757**

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G06F 17/50 (2006.01)
G01R 31/28 (2006.01)

(52) **U.S. Cl.** **716/12**; 716/6; 716/7; 716/13;
716/14; 716/17; 716/18

(58) **Field of Classification Search** 716/6,
716/7, 12-14, 17, 18; 714/725, 727, 736;
375/356; 365/201

See application file for complete search history.

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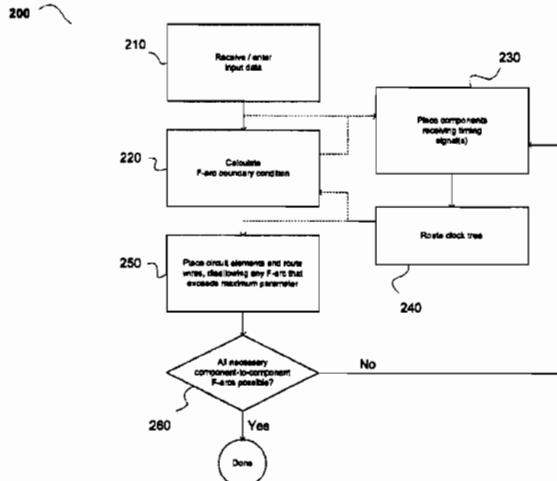
(74) *Attorney, Agent, or Firm*—The Law Offices of Andrew D. Fortney; Andrew D. Fortney

(57)

ABSTRACT

A method, software, and system for placing circuit elements and routing wires. The method, software, and system generally include the steps of (a) determining a boundary condition for signal paths between components in a circuit, wherein each of the components receives a clock signal and the signal paths include n wires and (n-1) circuit elements in alternating serial communication between the components, n being 2 or more; and (b) placing the circuit elements and routing the wires between the components and the circuit elements such that no signal path in the circuit exceeds the boundary condition. In preferred embodiments, the boundary condition is a maximum length, and the method further includes placing the clocked components in a floor plan such that no signal path can exceed the boundary condition. The present invention advantageously ensures that timing requirements for signal paths between clocked circuit components are met automatically.

36 Claims, 9 Drawing Sheets



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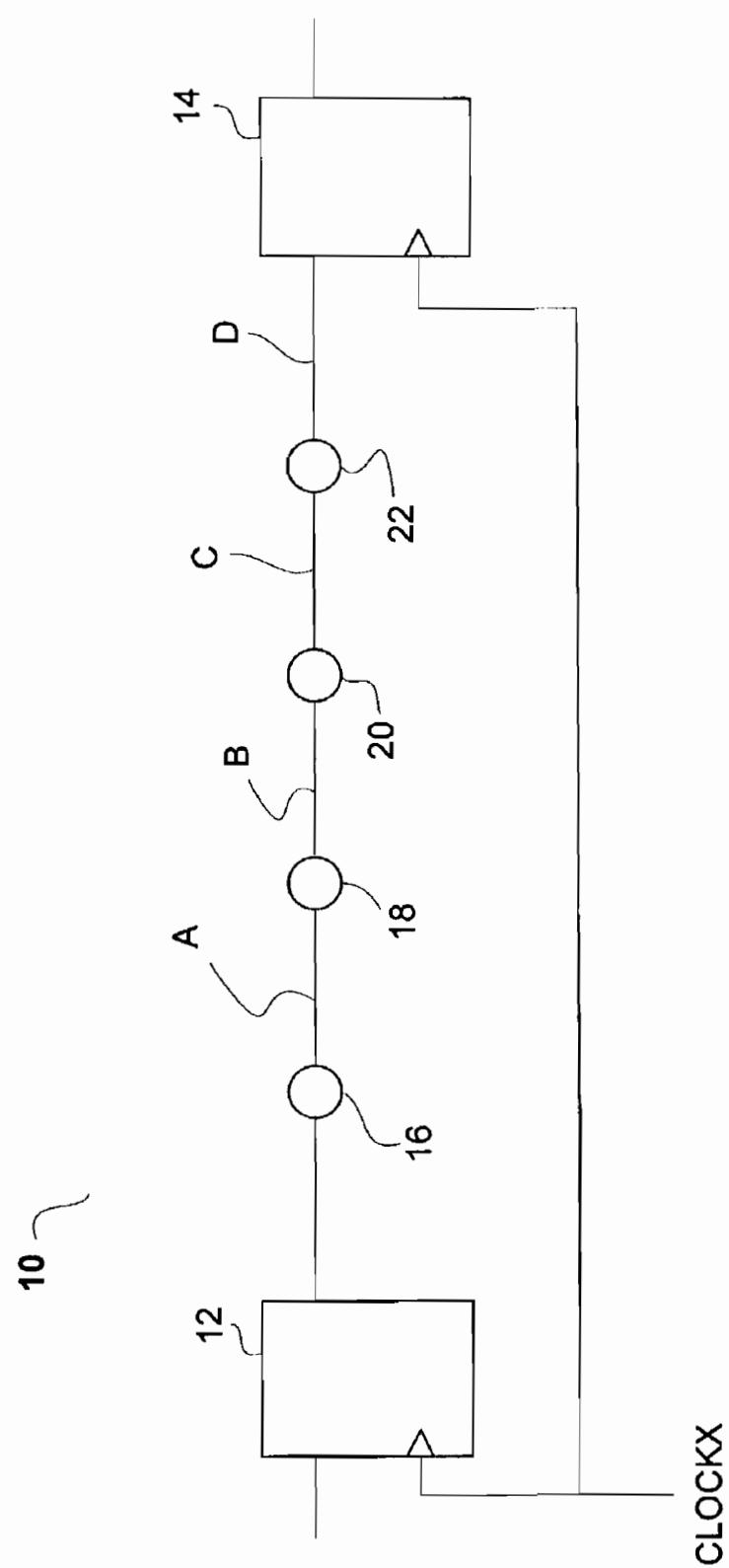
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FIG. 1

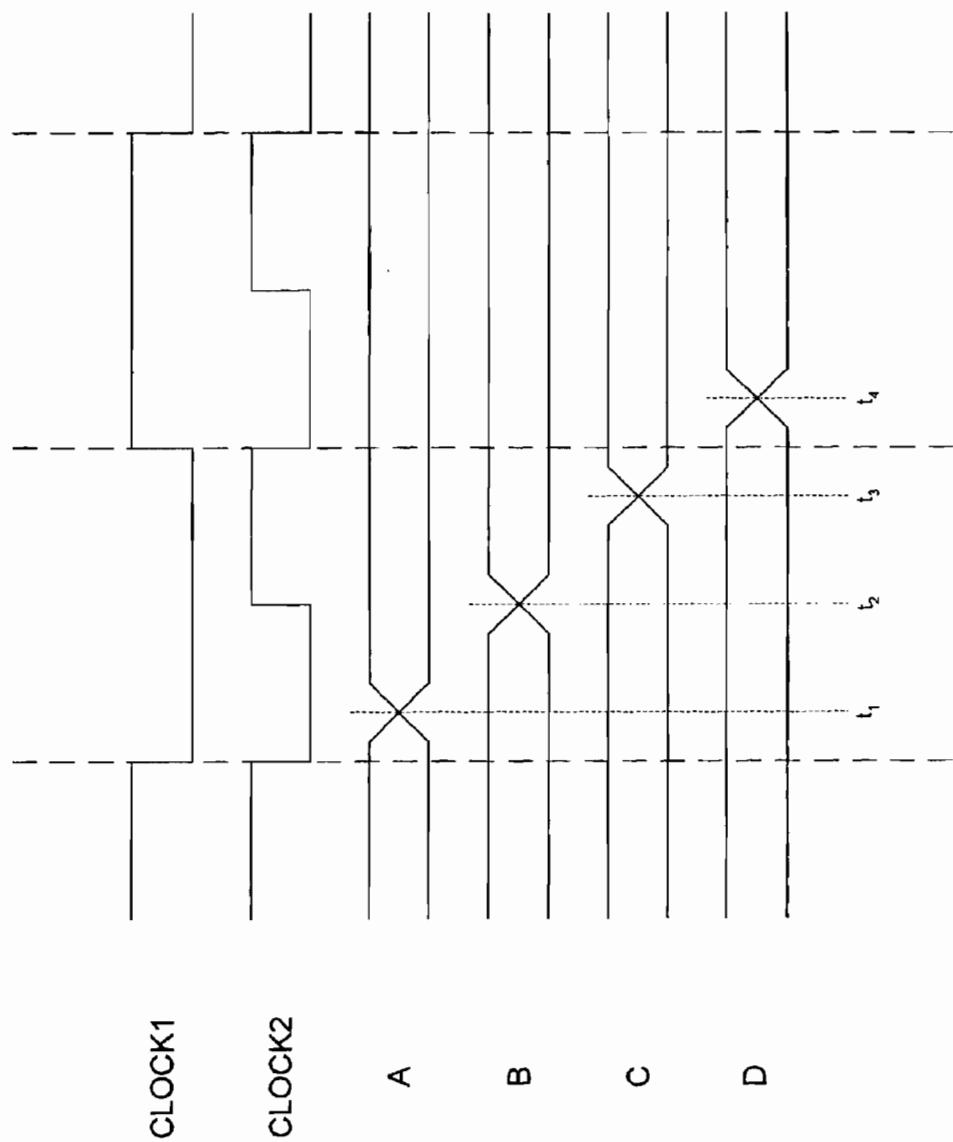
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FIG. 2



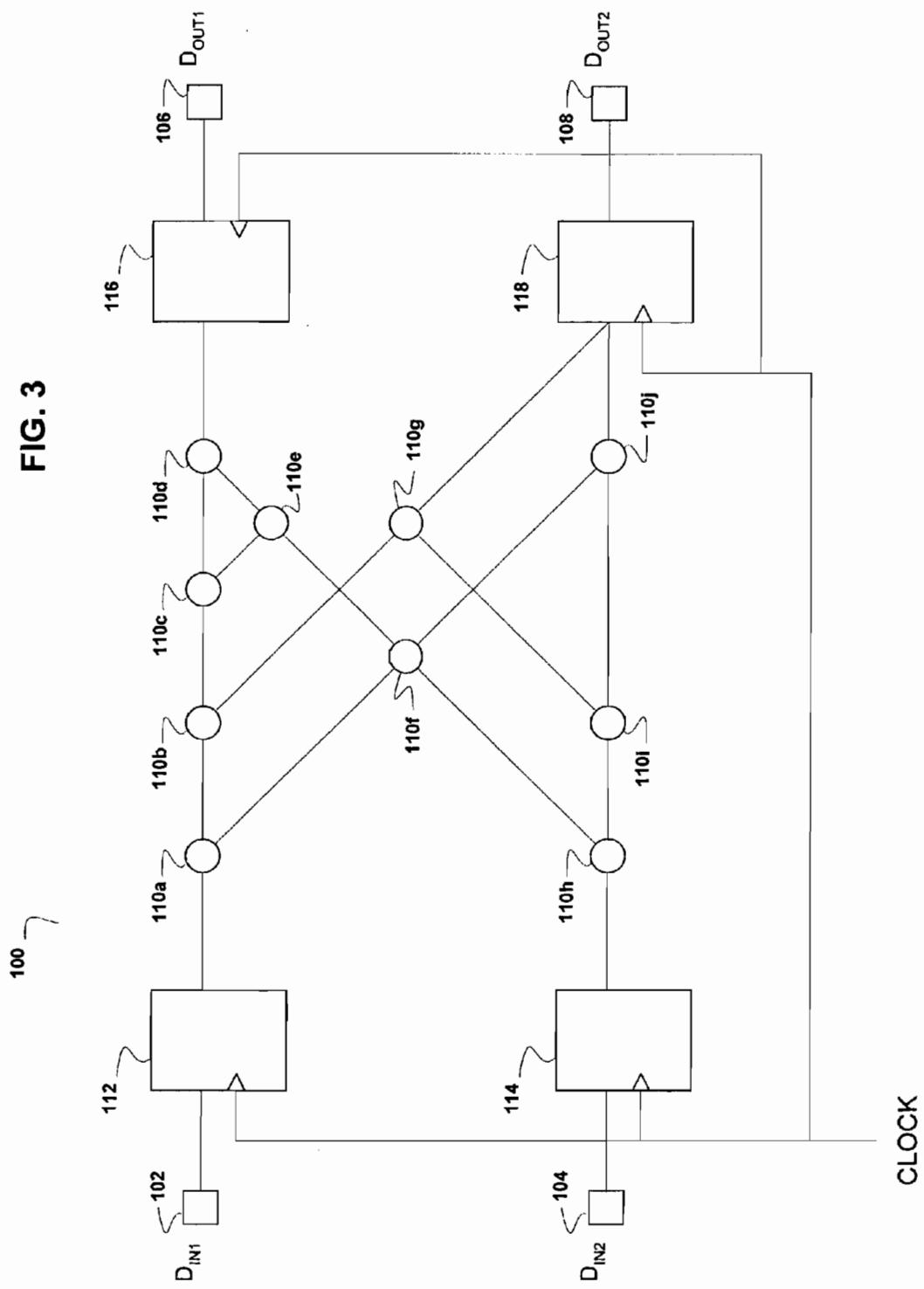
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FIG. 3

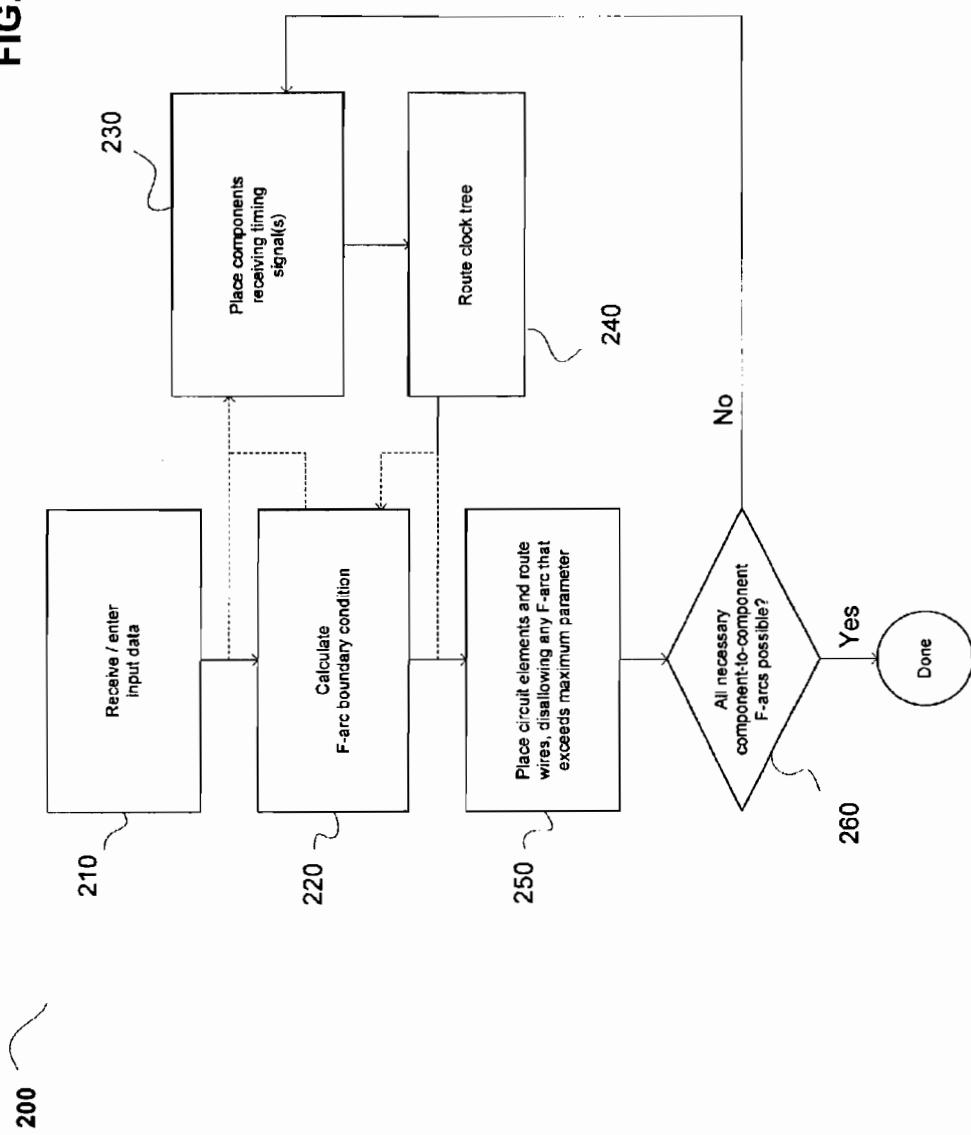


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FIG. 4

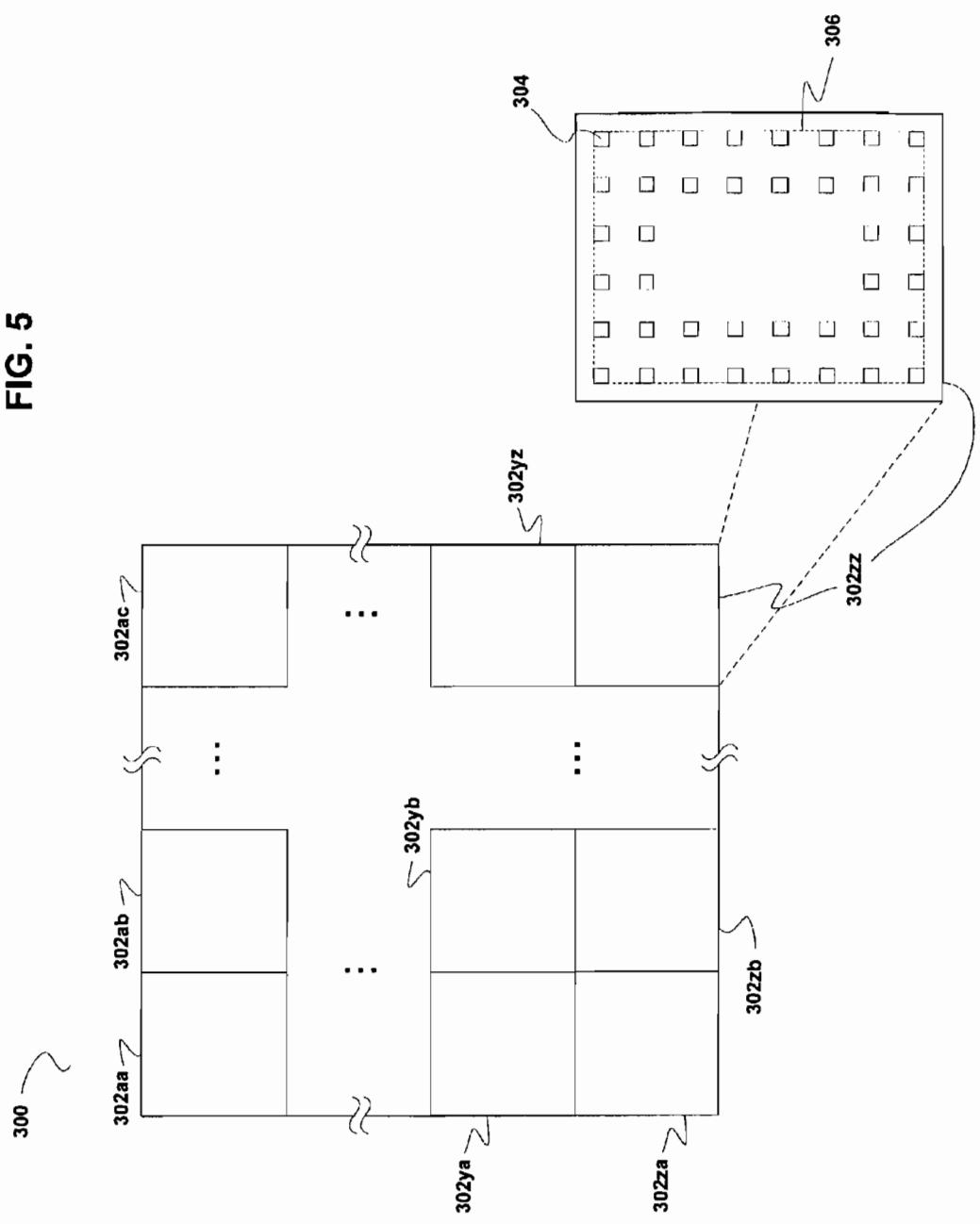
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FIG. 5

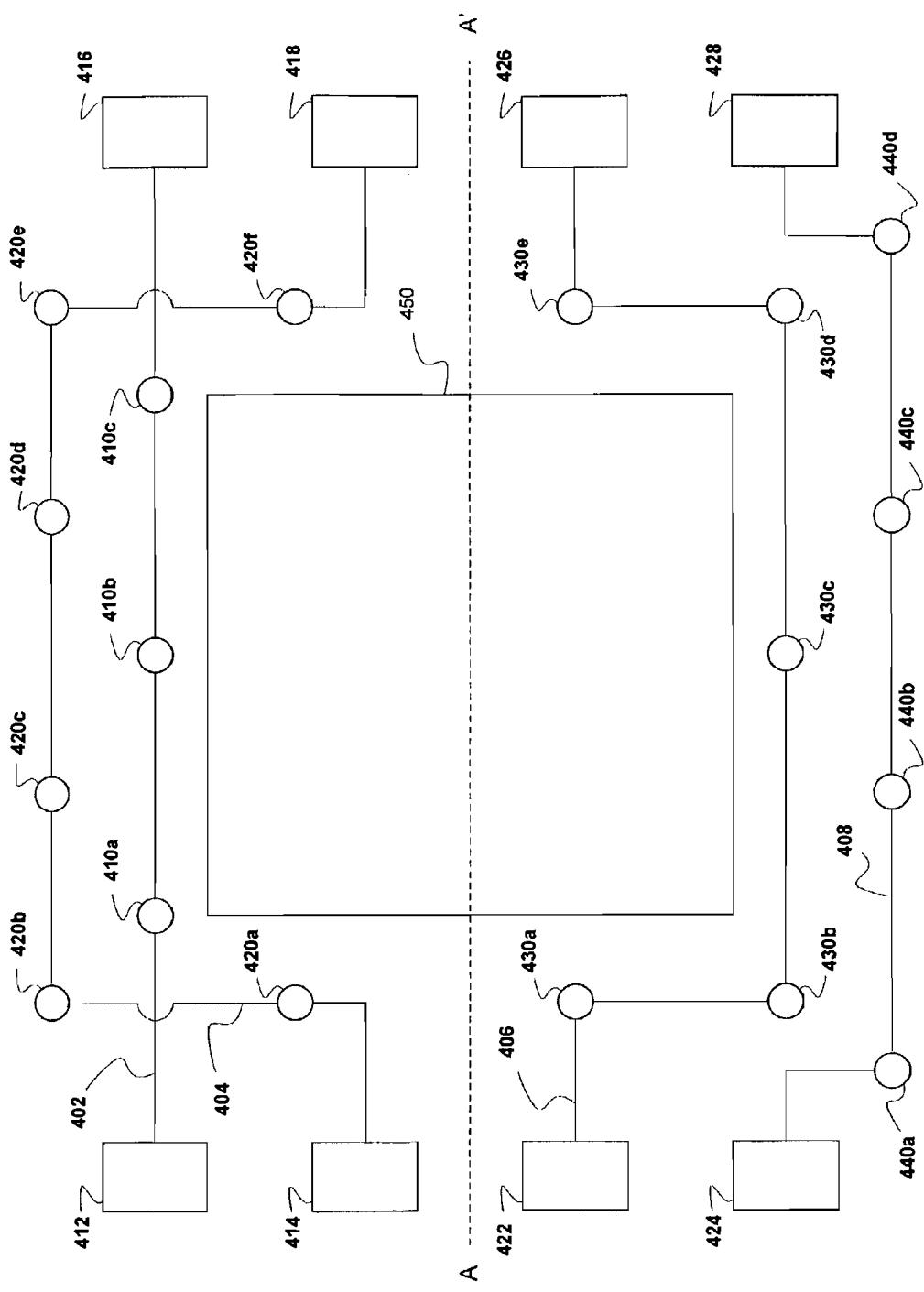


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FIG. 6

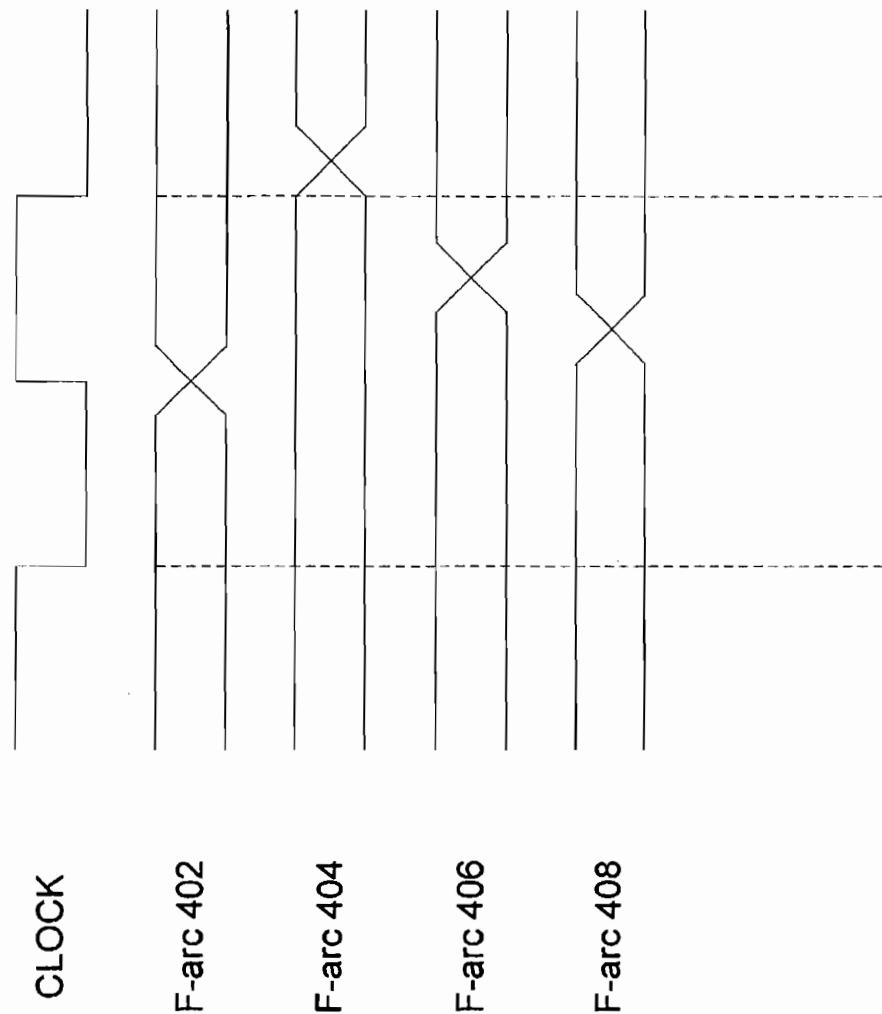
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FIG. 7

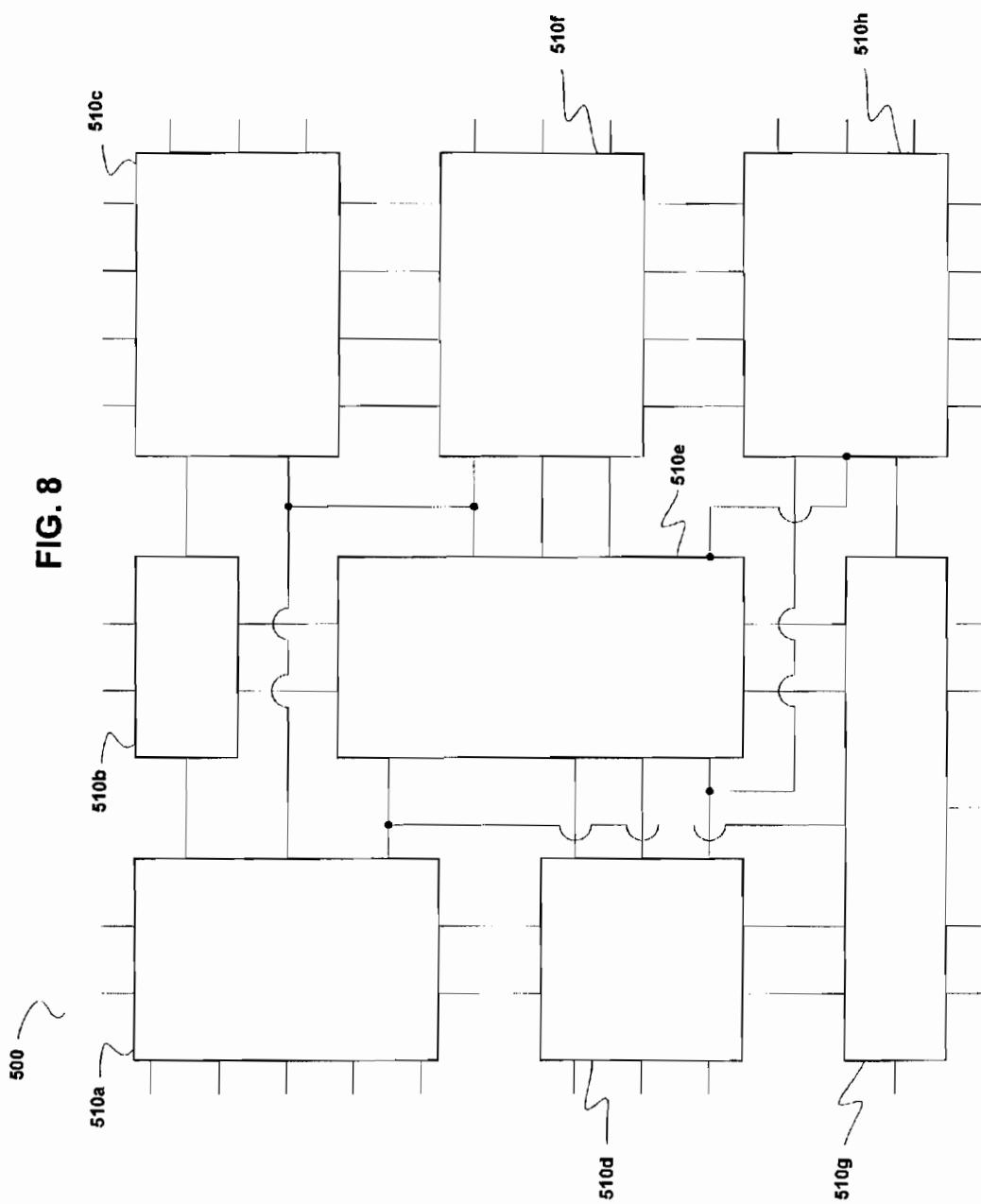


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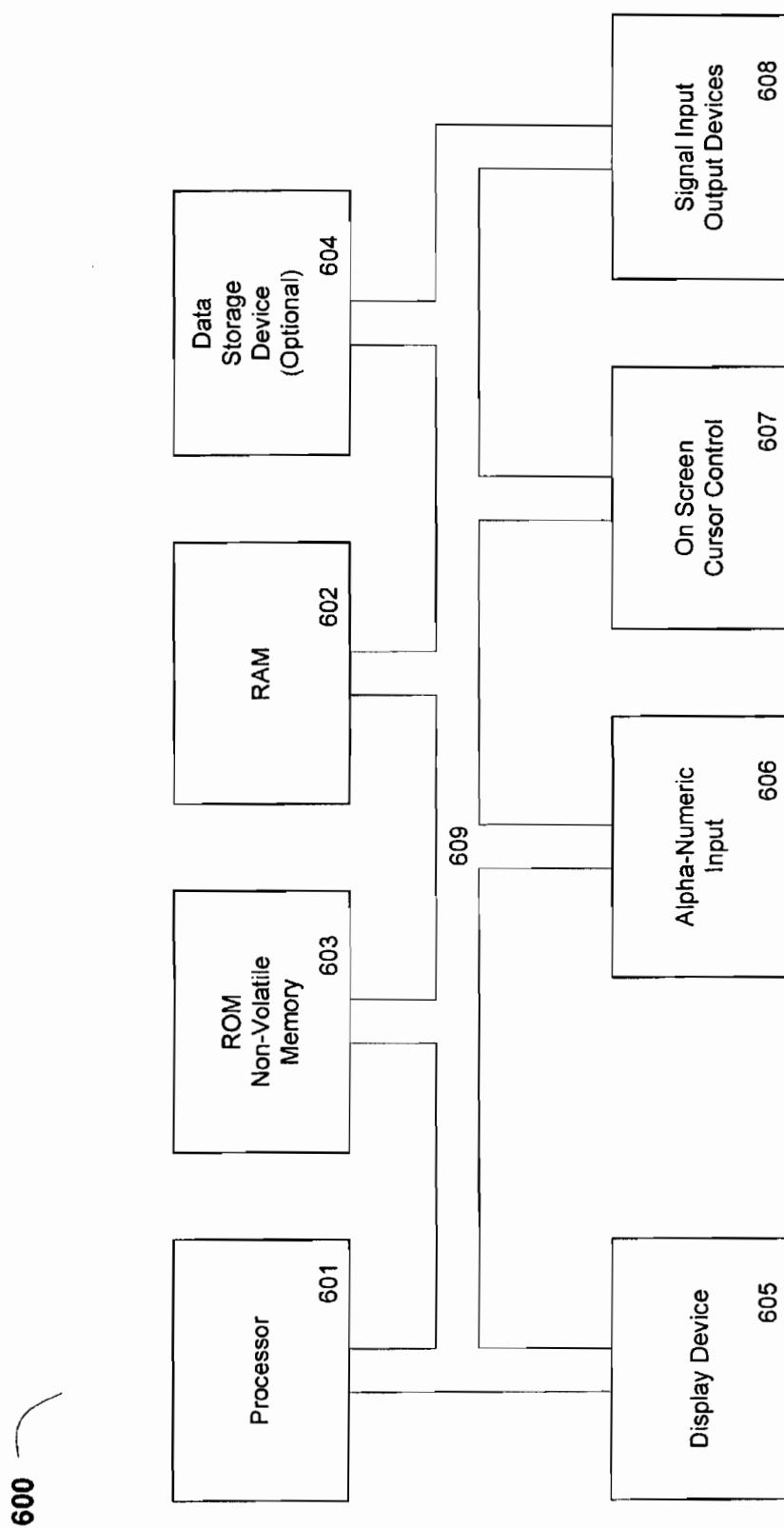


FIG. 9

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METHOD, SOFTWARE AND SYSTEM FOR ENSURING TIMING BETWEEN CLOCKED COMPONENTS IN A CIRCUIT

FIELD OF THE INVENTION

The present invention generally relates to the field of circuit design, particularly integrated circuit design. More specifically, embodiments of the present invention pertain to methods, algorithms, software, systems and architectures for improving timing in the design of an integrated circuit and/or ensuring that timing constraints in an integrated circuit are met.

DISCUSSION OF THE BACKGROUND

Traditionally, in the field of integrated circuit design, the length of time that a signal takes to go from a predetermined origin to a predetermined destination (herein, generally referred to as "timing") is an important parameter. Integrated circuit designers typically include contributions from (1) transistors and/or other circuit devices (such as capacitors, resistors, diodes, etc.) and (2) wires when predicting or evaluating the timing of a particular design. As line widths and device dimensions decrease, the relative contributions of wires to timing increase. At or below minimum or critical dimensions of 0.18 microns, wires become the major or dominant contributor to delays in timing.

Integrated circuits also generally have timing, or "clock," circuitry thereon. Such timing circuitry generally ensures that signals are captured at predetermined locations on the chip at certain times. The times at which certain circuit components capture data in the signals is generally defined by the clock signal waveform and the distribution of the clock signal to component locations on the chip.

Place and route software is generally used by integrated circuit designers to place circuit structures and/or configure wiring in a design automatically or semi-automatically. One typical challenge for place and route software has been to place circuit components (e.g., transistors, capacitors, diodes, logic gates, flip-flops, latches, registers, etc.) in a manner leaving sufficient room for wires to interconnect them. A number of such software tools are available in the marketplace today. However, such commercially available tools generally do not distinguish between clocked circuit components, such as flip-flops, latches and registers, and combinatorial circuit elements that do not receive a clock signal, such as switches and logic gates. Consequently, such tools generally do not ensure, or "guarantee by design," timing of signal paths from any clocked circuit component to the next downstream clocked circuit component. Rather, timing in a design is generally met by iteratively designing circuitry, then analyzing or determining the timing of various signal paths through the circuitry, and changing the design to shorten the signal paths that violate certain predetermined timing constraints or parameters.

Given the increasing demands on integrated circuit designers to create chips of increasing density, decreasing wire and transistor widths, and decreasing power supply and power consumption, it is difficult, if not impossible, to ensure meeting timing constraints automatically or "by design." Increasing the complexity, flexibility and/or functionality of the circuitry on a chip exacerbates these challenges. Thus, what is needed is a tool with which integrated circuit designers can ensure timing of signals from any given origin to any given destination in a circuit.

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SUMMARY OF THE INVENTION

Embodiments of the present invention relate to methods, algorithms, software, architectures and/or systems for placing circuit elements and/or routing wires in a circuit design, such that the design automatically meets timing constraints between circuit components receiving a clock signal.

The present invention advantageously ensures that timing requirements for signal paths between clocked circuit components (such as flip-flops and/or registers) are met automatically or "by design." In certain preferred embodiments, the invention helps to reduce power consumption, improve timing between circuit blocks and/or clock domains on an integrated circuit, improve pin-to-pin timing at a chip level, and/or reduce the total number of circuit elements and/or components in a design.

These and other advantages of the present invention will become readily apparent from the detailed description of preferred embodiments below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a box diagram showing an exemplary F-arc.

FIG. 2 is a set of waveforms for illustrating how the invention operates with respect to the F-arc of FIG. 1.

FIG. 3 is a box diagram showing a relatively simple, exemplary array of gates between two pairs of flip-flops, in which the present invention may be implemented.

FIG. 4 is a flow chart outlining the steps taken in one embodiment of method and/or algorithm of the present invention.

FIG. 5 is a diagram showing a preferred embodiment of the present invention.

FIG. 6 shows a simplified layout showing a number of signal paths between clocked circuit components, further illustrating an exemplary operation of the present invention.

FIG. 7 is a set of waveforms for illustrating how the invention operates with respect to the layout of FIG. 6.

FIG. 8 is an exemplary box-level chip design, in which the present invention may be implemented.

FIG. 9 is an exemplary computer system, in which the present invention may be implemented.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. While the invention will be described in conjunction with the preferred embodiments, it will be understood that they are not intended to limit the invention to these embodiments. On the contrary, the invention is intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope of the invention as defined by the appended claims. Furthermore, in the following detailed description of the present invention, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be readily apparent to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components, and circuits have not been described in detail so as not to unnecessarily obscure aspects of the present invention.

Some portions of the detailed descriptions which follow are presented in terms of processes, procedures, logic blocks, functional blocks, processing, and other symbolic represen-

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tations of operations on code, data bits, data streams or waveforms within a computer, processor, controller and/or memory. These descriptions and representations are generally used by those skilled in the data processing arts to effectively convey the substance of their work to others skilled in the art. A process, procedure, logic block, function, process, etc., is herein, and is generally, considered to be a self-consistent sequence of steps or instructions leading to a desired and/or expected result. The steps generally include physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical, magnetic, optical, or quantum signals capable of being stored, transferred, combined, compared, and otherwise manipulated in a computer or data processing system. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, waves, waveforms, streams, values, elements, symbols, characters, terms, numbers, or the like, and to their representations in computer programs or software as code (which may be object code, source code or binary code).

It should be borne in mind, however, that all of these and similar terms are associated with the appropriate physical quantities and/or signals, and are merely convenient labels applied to these quantities and/or signals. Unless specifically stated otherwise and/or as is apparent from the following discussions, it is appreciated that throughout the present application, discussions utilizing terms such as "processing," "operating," "computing," "calculating," "determining," "manipulating," "transforming," "displaying" or the like, refer to the action and processes of a computer or data processing system, or similar processing device (e.g., an electrical, optical, or quantum computing or processing device), that manipulates and transforms data represented as physical (e.g., electronic) quantities. The terms refer to actions and processes of the processing devices that manipulate or transform physical quantities within the component(s) of a system or architecture (e.g., registers, memories, other such information storage, transmission or display devices, etc.) into other data similarly represented as physical quantities within other components of the same or a different system or architecture.

Furthermore, in the context of this application, the terms "net list" and "hardware description" may be used interchangeably to refer to a circuit design represented in an appropriate language, such as VERILOG, HDL or VHDL. Similarly, the terms "wire," "wiring," "line," "signal," "conductor" and "bus" refer to any known structure, construction, arrangement, technique, method and/or process for physically transferring a signal from one point in a circuit to another. Also, unless indicated otherwise from the context of its use herein, the terms "known," "fixed," "given," "certain" and "predetermined" generally refer to a value, quantity, parameter, constraint, condition, state, process, procedure, method, practice, or combination thereof that is, in theory, variable, but is typically set in advance and not varied thereafter when in use.

Similarly, for convenience and simplicity, the terms "clock," "time," "timing," "rate," "period" and "frequency" are, in general, interchangeable and may be used interchangeably herein, but are generally given their art-recognized meanings. Also, for convenience and simplicity, the terms "data," "data stream," "waveform" and "information" may be used interchangeably, as may (a) the terms "flip-flop," "latch" and "register," and (b) the terms "connected to," "coupled with," "coupled to," and "in communication with," but these terms are generally given their art-recognized meanings herein.

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The present invention concerns a method and/or algorithm (e.g., a computer-readable set of instructions) for placing circuit elements and routing wires, comprising the steps of (a) determining a boundary condition for signal paths between components in a circuit, wherein each of the components receives a clock signal and a plurality of the signal paths comprise n wires and $(n-1)$ circuit elements in alternating serial communication between the components, n being an integer of 2 or more; and (b) placing the circuit elements and routing the wires between the components and the circuit elements such that no signal path in the circuit exceeds the boundary condition. In preferred embodiments, the boundary condition comprises a maximum length, and the method further comprises placing the clocked components in a floor plan such that no signal path in said circuit can exceed said boundary condition.

In a further aspect of the invention, the method relates to verifying a circuit design, comprising the steps of determining whether, in a floor plan corresponding to said circuit, any of a plurality of signal paths between components receiving a clock signal exceeds a boundary condition, where each of the signal paths comprise n wires and $(n-1)$ circuit elements in alternating serial communication, n being an integer of 2 or more; and if any of said signal paths exceeds said boundary condition, then (i) re-placing at least one of said circuit elements and/or said circuit components in a different location in said floor plan, and (ii) re-routing said wires between replaced circuit elements and/or circuit components such that no signal path in said circuit exceeds said boundary condition.

In a further aspect of the invention, the software relates to a medium or waveform containing a computer-readable set of instructions, where the instructions comprise (a) calculating a boundary condition for all signal paths between components in a circuit, wherein each of said components receives a

timing signal in a common clock domain and a plurality of said signal paths independently comprise n wires and $(n-1)$ circuit elements in alternating serial communication between said components, n being an integer of 2 or more; and (b) placing said circuit elements and routing said wires between said components such that no signal path in said circuit exceeds said boundary condition. In an even further aspect of the invention, the system comprises a general purpose computer or workstation that includes the present software and is configured to execute the steps of the present method(s) and/or algorithm(s).

In a further aspect of the invention, the chip or circuit architecture comprises at least one block of circuitry having a plurality of signal paths, each of the signal paths comprising

(a) first and second components at the endpoints thereof, and

(b) at least two wires and at least one combinational circuit element alternately, serially coupled between said first and second components, wherein each component receives a

clock signal and each signal path does not exceed a predetermined boundary condition.

The invention further relates to hardware and/or software implementations of the present architecture, method and system. The invention, in its various aspects, will be explained in greater detail below with regard to exemplary embodiments.

60 F-Arcs and an Exemplary Implementation of the Invention

FIG. 1 shows a simple signal or data path 10 from a first circuit component 12 receiving a clock signal (e.g., CLOCKX) to a second circuit component 14 receiving the same clock signal. Between first and second circuit components 12 and 14 are circuit elements 16, 18, 20 and 22.

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Signal/data path 10 is a very simple example of an F-arc. Generally, an "F-arc" is considered herein to be a signal path having two components at its endpoints and a series of alternating wires and combinational circuit elements between the two components, where the components receive a common clock signal (e.g., the same clock or logically equivalent clocks).

First and second circuit components 12 and 14, which may be the same or different, are generally any circuit or device configured to operate under the control of, or in response to, a clock signal. First and second circuit components 12 and 14 may be edge- or voltage level-controlled or -triggered. Examples of suitable circuit components include storage or memory components, such as a flip-flop, a latch or a register; switches or gates, such as a transistor configured to receive the clock signal at its gate; a counter; a synchronous adder or subtractor; a divider or multiplier; parallel combinations thereof; etc. Preferably, circuit components receiving a clock signal comprise a flip-flop or a register.

Circuit elements 16, 18, 20 and 22, which may be independently selected, are generally any circuit or device not configured to receive a clock signal. Suitable examples include an inverter or a buffer (e.g., an even-numbered series of inverters, typically 2 inverters in series, which may be 3-statable or configured to be placed in a "high z" state); a switch or transistor receiving a control signal (other than a clock) at its gate; a logic gate (such as an AND, OR, NAND, NOR, or XOR gate); a multiplexer or demultiplexer; a comparator, encoder or decoder; an combinational adder or subtractor; parallel or serial combinations thereof; etc. While the invention focuses on F-arc signal paths having at least one circuit element therein, preferably the signal paths include at least 2 circuit elements, and more preferably at least 3 circuit elements. While the upper limit of circuit elements is constrained only by the design and fabrication technology available, typical upper limits in a 0.15 or 0.18 micron fabrication technology and design are on the order of 15-20 circuit elements.

Similarly, the length of wires has upper and lower limits constrained only by the design and fabrication technology available. However, typical lower limits in a 0.15 or 0.18 micron fabrication technology and design are on the order of $4 \times$ the minimum feature dimension of the immediately underlying layer (e.g., for a 0.15 micron wide transistor, a minimum length for the first layer of metal is about 0.6 microns), while typical upper limits in a 0.15 or 0.18 micron fabrication technology and design are on the order of about 1000 microns (preferably about 500 microns).

In general, the invention relies on a boundary being placed on the maximum length of an F-arc. This maximum length may be based on input data relating to characteristic properties of the fabrication process used to make the circuit and/or provide timing signals to the circuit. Such input data generally include (i) a period or frequency of the clock signal, (ii) a resistivity of the wire in the F-arc, (iii) an operating voltage and/or (iv) a characteristic resistivity or time delay contributed by each circuit element in the F-arc. However, for design rules at or below 0.18 microns, the characteristic resistivity or time delay contributed by each circuit element may be negligible in comparison with the time delays contributed by the wires, and may be ignored or taken into account by a simple approach. For convenience and/or simplicity, one may simply factor in a potential maximum delay that could be caused by a combination of circuit elements and processing and operational "corners" (e.g., processing and/or fabrication variations, operating voltage fluctuations, etc.), and decrease the appli-

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cable length of time (e.g., the clock period or fraction or multiple thereof) by that potential maximum delay.

In certain embodiments, the method and/or algorithm further include identifying, defining or specifying an F-arc as 5 any combinational path between two clocked circuit components. One skilled in the art understands how to identify in a net list (or hardware description) circuit components receiving a clock signal, combinational circuit elements and wires (or "nets") between such combinational circuit elements or 10 between such a circuit component and a combinational circuit element. One skilled in the art understands also how to write code (which in one embodiment, may be source code) that will predict certain properties and/or characteristics for F-arcs, compare such properties and/or characteristics for 15 each F-arc identified against a boundary and determine whether each such F-arc is allowed or disallowed, and (iteratively) re-place circuit components and elements and/or re-route wires so that all identified F-arcs are allowed. The boundary condition identified against each F-arc may be 20 determined empirically.

The wires themselves may directly link only two combinational circuit elements or a combinational circuit component and a combinational circuit element, or they may be branched (e.g., linking a combinational circuit element to two 25 or more combinational circuit elements or vice versa, or a clocked circuit component to two or more combinational circuit elements or vice versa). The inventive method also encompasses further embodiments where the signal path in an additional F-arc has no combinational circuit elements, but 30 instead, includes only a wire (which may comprise two or more segments as discussed above).

Furthermore, there is no maximum limit to the number of F-arcs to which the method and/or algorithm can be applied. However, circuit designers generally attempt to keep designs 35 as small as possible and/or feasible, while still achieving desired functionality and/or performance. These "natural" constraints will generally tend to limit the number of F-arcs in a circuit, circuit block or chip design. However, in a typical design of moderate to high complexity, there will be at least a 40 million F-arcs to be placed and routed, frequently several million F-arcs or more, and occasionally 10 million or more F-arcs.

In the simplest case, the boundary placed on the F-arc corresponds to the period of one clock cycle. In other words, 45 an F-arc violates the boundary condition if it takes longer than one clock cycle for a signal to traverse the F-arc. Of course, other boundary conditions may apply, such as one-half of a clock cycle (e.g., for two components defining the endpoints of an F-arc that receive complementary clock signals CLOCK 50 and CLOCKb), or x clock cycles, where x is an integer of at least 2. One skilled in the art is capable of designing circuitry configured to account for and/or control such conditions.

The wire resistivity is generally known from the process 55 technology to be used for fabricating the device being designed. The wire resistivity may be characterized as a sheet resistivity, a bulk resistivity, or other known resistance or resistivity parameter, and it may be calculated for a given wire from such resistance or resistivity and the height and width of the wire (which are also known for a known process technology).

The time delay is generally a constant value for a given 60 circuit element having certain dimensions in a known process technology. For example, a transistor of a known type and having predetermined dimensions in a given process technology will generally cause a delay of known or calculable length in a signal changing states. Furthermore, operating voltages are generally standard or predetermined values for a

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given minimum transistor dimension (generally width). As a result, a given set of design rules for a given process technology will generally have a fixed and/or predetermined operating voltage.

Now referring to FIG. 2, two different exemplary waveforms, CLOCK1 and CLOCK2, are shown for the generic clock signal, CLOCKX. CLOCK1 has a relatively long period and low frequency, and CLOCK2 has a relatively short period and high frequency. Although the exemplary clock signal CLOCK1 is shown having a period twice that of CLOCK2, this is simply for ease of illustration only.

The state of a signal along exemplary F-arc 10 can be determined at nodes A, B, C and D (respectively, along the wires immediately downstream from circuit elements 16, 18, 20 and 22) at certain times. As shown by the waveforms in FIG. 2, component 12 is a negative edge-triggered component. The state of the signal at node A may change a certain time t_1 after CLOCKX changes state. Similarly, the state of the signal at nodes B, C and D may change a certain time t_2 , t_3 and t_4 , respectively, after the negative edge of CLOCKX is received at component 12. To a first approximation, the signal is received by component 14 immediately after the characteristic time that node D can change state, t_4 .

In this example, for simplicity, the maximum F-arc length is determined in part on a one clock period length of time. When CLOCK1 is operable, t_4 is less than one period of CLOCK1, and the length of F-arc 10 falls comfortably below the CLOCK1-defined maximum. On the other hand, since t_4 is greater than one period of CLOCK2, when CLOCK2 is operable, the length of F-arc 10 exceeds the boundary condition defined in part by the CLOCK2 period.

F-arcs that exceed the maximum length boundary are disallowed. By doing so, the present invention ensures that signal propagation timing requirements are met in a circuit, circuit block and/or circuit design receiving a particular clock. In the present invention, the clock signal need not be the same signal for all timing-controlled components on a chip, only that the signal or a logical equivalent thereof (e.g., an integer multiple and/or divisor thereof, complement thereof, etc.) be supplied to all such components within a given circuit or block of circuitry. In other words, the invention applies a maximum boundary condition on all F-arcs within a common clock domain.

Thus, in one aspect, the invention concerns a method of placing and routing, comprising the steps of (a) determining a maximum length of a signal path between components in a circuit, and (b) placing circuit elements and routing wires between the components such that no signal path in the circuit has a length exceeding the maximum length. In the invention, the signal path generally contains two or more wires and one or more circuit elements, and each of the components receives a clock signal. Generally, the circuit elements do not receive the clock signal.

In further embodiments, the method further includes the step(s) of routing or distributing the clock signal to the components; placing the components and/or circuit elements in a floor plan corresponding to said circuit; and/or routing the wires from a first component to one or more first circuit elements, and from one or more first circuit elements to either one or more second circuit elements or said second component. In even further embodiments, wires can be routed along any number of circuit elements, as long the final wire in the signal path is to a second component and as long as the maximum boundary condition on F-arcs is not violated.

Alternatively, as will be readily apparent to those skilled in the art, a maximum F-arc length is but one boundary condition encompassed by the present invention. Other exemplary

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F-arc boundary conditions, which may be related to time, length, resistance and/or other physical properties of an F-arc, include a maximum time or delay for signal propagation along the F-arc, a maximum resistance and/or capacitance, a maximum or minimum inductance, a maximum and/or minimum impedance (depending on the states of the F-arc, the second component and/or the circuitry downstream from the second component), etc.

Exemplary Application #1

Referring now to FIG. 3, a functional circuit block 100 may comprise an array of logic elements 110a-110j that process data signals D_{IN1} and D_{IN2} , respectively received at input nodes 102 and 104, and outputs data signals D_{OUT1} and D_{OUT2} at output nodes 106 and 108, respectively. Data signals D_{IN1} and D_{IN2} are clocked into flip-flops 112 and 114, and data signals D_{OUT1} and D_{OUT2} are clocked out of flip-flops 116 and 118, by a timing signal CLOCK. As mentioned above, flip-flops 112, 114, 116 and 118 are exemplary circuit components receiving a timing signal within a common clock domain, and logic elements 110a-110j are examples of circuit elements (generally comprising one or more transistors, or preferably, one or more buffers) that do not receive a clock signal. Thus, for the purposes of explaining the invention, circuit elements that do not receive a clock signal may be considered "combinational."

The circuit elements are electrically coupled to each other and to circuit components by wires, as shown in FIG. 3. When actually fabricated, the wires may be located on the same or different layers of metallization in the chip, and may individually comprise one or more wire segments, electrically coupled to each other and/or to circuit elements by contacts or vias. Each of the wire segments and the contacts or vias contributes to the length and/or propagation/delay time of the F-arc. Furthermore, there is no defined or specific relationship between the locations of circuit element depictions 110 in FIG. 3 and the locations of actual, physical circuit elements in the fabricated chip. However, there may be a general correlation in that circuit element depictions 110 that are proximate to each other in FIG. 3 (e.g., 110c and 110b) are likely to correspond to physical circuit elements that are proximate to each on the fabricated chip (or at least relatively closer to each other than to relatively distant circuit elements in the depiction in FIG. 3), and circuit element depictions 110 that are relatively distant from each other in FIG. 3 (e.g., 110a and 110j) are likely to correspond to physical circuit elements that are relatively distant from each other on the fabricated chip.

In another aspect, the present invention concerns a method, algorithm and software that determines or calculates an F-arc boundary condition from certain input data, then places combinational circuit elements and routes wires that enable electrical communication to form F-arcs such that F-arcs that exceed the boundary condition are disallowed. A flow chart outlining an exemplary embodiment 200 of the method and/or algorithm is shown in FIG. 4.

In the general method and/or algorithm of the invention, input data relating to characteristic properties of the fabrication technology and/or timing signals for the circuit being designed are input into the design software (see step 210 of FIG. 4). In some embodiments, such input data may be automatically generated and/or received by the design software by selection or designation of the fabrication process and/or operating frequency of an internal or external (master) clock signal. From this input data, the F-arc boundary condition is calculated (see step 220 of FIG. 4). In preferred embodiments, the F-arc boundary condition is a maximum length or maximum time delay, more preferably a maximum length.

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In parallel or in serial fashion, components of the circuit receiving a clock or timing signal are placed in a floor plan corresponding to the physical circuit being designed. In one embodiment, such components are placed without reference to the F-arc boundary condition (e.g., before determining or calculating the F-arc boundary condition, or in parallel with such determination or calculation). In another (and preferred) embodiment, the method and/or algorithm places such components in the floor plan in a manner disallowing any placement that will exceed or violate the boundary condition (e.g., components are placed after determining or calculating the F-arc boundary condition). Now referring to FIG. 5, in an even more preferred embodiment, the floor plan 300 comprises a plurality or array of tiles 302aa-302zz, and the method and/or algorithm places components 304 in at least a subset of the tiles in an array or a regular or evenly-spaced pattern 306 (also see U.S. patent application Ser. No. 10/452, 811, filed May 30, 2003 and incorporated herein by reference).

Referring back to FIG. 3, components 112, 114, 116 and 118 have been placed with regular spacing between components. For example, the distance between individual "input" components (i.e., components 112 and 114) is the same as the distance between individual "output" components (i.e., components 116 and 118). Also, the distance between any "input" component and its nearest "output" component (e.g., components 112 and 116, or 114 and 118) is the same. However, the invention is not so constrained; clocked circuit components can be placed in any allowed location, preferably such that the F-arc boundary condition is not violated. Thus, all of the possible signal paths in FIG. 3, from any "input" component to any "output" component along any possible series of wires and circuit elements 110, have a length below the maximum allowed F-arc length.

Thus, the invention is not only useful for preventing disallowed F-arcs (e.g., ensuring intra-circuit timing between clocked components "by design"), but also for detecting or finding erroneously placed and/or routed F-arcs, and optionally, replacing components or combinational circuit elements and rerouting wires to correct such design errors. Consequently, in further embodiments, the inventive method and/or algorithm may be included as part of a circuit design verification tool, in which timing of a fully placed and routed circuit is verified at a number of levels, from chip input pin to chip output pin, circuit block input node to circuit block output node, clock domain input node to clock domain output node, and/or (as described herein) F-arc input component to F-arc output component.

Although specific steps are disclosed in regard to the operation of the exemplary method and/or algorithm of FIG. 4, such steps are exemplary. That is, the present invention is well suited to use with various other steps or variations of the steps described above. Additionally, for purposes of clarity and brevity, the discussion herein is directed at times to specific examples. The present invention, however, is not limited solely to use with a particular architecture, method, process, software tool or device. Instead, the present invention is well suited to use with other architectures, software, circuitry, methods and processes in which it may be desirable to accomplish a multitude of tasks as part of an overall process directed at ensuring timing at a clocked circuit component level.

Further examples of suitable systems, tools and/or methods in which the present invention is generally applicable include those described in, e.g., U.S. Pat. Nos. 6,080,201, 6,212,489, 5,798,936 and 5,550,748, the relevant portions of which are each incorporated herein by reference, and those commercially available from place-and-route software vendors such

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as Cadence Design Systems (e.g., the SILICON ENSEMBLE™, SILICON ENSEMBLE-PK™, FIRST ENCOUNTER™, and NANO ENCOUNTER™ tools), Silicon Valley Research, Inc. (e.g., the QIC/AP™, GARD™, SCT™ and FLOORPLACER™ tools), Synopsis (e.g., the CHIP ARCHITECT™, DESIGN COMPILER™, and FLOORPLAN COMPILER™ tools) and Mentor Graphics (e.g., the AUTOCELLS™ tool).

Exemplary Application #2

FIG. 6 shows a simplified, exemplary circuit layout 400 comprising F-arcs 402, 404, 406 and 408, for further illustrating the present invention. In general, component and signal/bus numbers common to both FIGS. 3 and 6 reflect the suitability of the same structures, signals and/or functions for both of the exemplary embodiments. However, these examples do not require that the same component(s), signal(s), bus(es) and/or function(s) be used or implemented in both examples, other than as specifically described herein.

Input data or signals are received by clocked circuit components 412, 414, 422 and 424, which store or hold the data or signal on the appropriate edge, transition and/or logic level of the clock, in accordance with conventional design. For clarity, the clock signal is not shown in FIG. 6. The data or signals are propagated in parallel through a series of combinational circuit elements 410a-410c, 420a-420f, 430a-430e and 440a-440d, and are input into or stored in "output" components 416, 418, 426 and 428 on the next appropriate clock edge or level. Block 450 is a disallowed placement area (e.g., it is devoted to a circuit function such as memory/storage, signal and/or data processing, clock signal generation, power/current transmission, etc.).

One issue the invention addresses is placing circuit components and elements and routing wires around disallowed placement areas. Again, for purposes of illustrating the invention, input components 412 and 414 are complementary to input components 422 and 424 with respect to the A-A' axis bisecting disallowed placement area 450, and output components 416 and 418 are similarly complementary to output components 426 and 428. If a circuit design requires routing signals from a set of input components, around bisecting disallowed placement area 450, to a set of output components, the invention provides a tool by which such routing can be accomplished while ensuring that timing constraints are met at the level of clocked components, such as flip-flops, latches and registers.

Referring now to FIG. 7, for purposes of illustration, the F-arc boundary is based on a one clock period length of time. F-arc 402, which is relatively short in comparison to the other F-arcs of FIG. 6, easily falls below the boundary condition. However, F-arc 404, which is relatively long in comparison to the other F-arcs of FIG. 6, exceeds the boundary condition. Such a circuit element placement and wire routing would be disallowed by the present invention.

On the other hand, F-arcs 406 and 408, which have lengths intermediate to those of F-arcs 402 and 404, both fall below the boundary condition. Consequently, this placement is allowed by the present invention, and the present invention would automatically place combinational circuit elements and wires (and optionally, components receiving a clock signal) in this manner rather than as shown for F-arcs 402 and 404.

An Exemplary Chip Architecture and/or Design

FIG. 8 shows an exemplary architecture and/or a chip-level design 500, comprising a plurality of functional blocks and/or clock domains 510a-510i, wherein at least 1 (and preferably at least 2) of the functional blocks and/or clock domains are designed according to the method(s) described above. Func-

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tional blocks and/or clock domains **510a-510i** are individually connected with other functional blocks and/or clock domains via wires or busses, which may be single bit or multi-bit, and which may comprise a single wire segment or multiple wire segments as described above. In general, a "functional block" is a block of circuitry that physically occupies an area on a chip defined by a single border (although the border may be arbitrary in shape and/or dimensions), and a "clock domain" is circuitry that receives a common clock signal or its logical equivalent, in order to have certain events within the circuitry occur at expected and/or predetermined times. Preferably, the invention applies to a chip having at least 2 clock domains, and each clock domain comprises one or more functional blocks.

This, the invention further relates to a chip architecture, in which at least one block of circuitry comprises a plurality of signal paths, each of the signal paths having first and second components at the endpoints thereof and comprising at least 2 wires and at least 1 combinational circuit element alternately and serially coupled between the first and second components, in which each component receives a clock signal (the same clock signal or a logical equivalent thereof) and each signal path does not exceed a predetermined boundary condition. In preferred embodiments, the block of circuitry comprises components that are regularly spaced from the nearest component thereto, and the boundary condition comprises a maximum length.

Naturally, the invention is not limited to a design having the same number or configuration of blocks **510** and/or wires. However, in preferred embodiments, the chip design has at least 2 such blocks, more preferably at least 4 such blocks, that are coupled at least to physically adjacent blocks by either (i) a plurality of single-bit wires, or (ii) at least one multi-bit bus. For example, in FIG. 8, blocks **510a-c** may each operate according to a common clock signal, in which case at least one of the wires between blocks so operating electrically communicates the clock signal from one block to the other block. In addition, blocks **510d-i** may each operate in a common clock domain, in which case one of the blocks provides a clock generation, clock replication and/or clock recovery function, and at least one of the wires from the block providing such clock function(s) to the other block(s) electrically communicates the generated, replicated and/or recovered clock signal.

An Exemplary System for Performing the Present Method

Referring now to FIG. 9, in a further aspect of the invention, the system comprises at least one computer system **600**, which may form a platform for practicing embodiments of the invention. Computer system **600** includes an address/data bus **609** for communicating information, a central processor **601** coupled with the bus for processing information and instructions, a volatile memory **602** (e.g., random access memory or RAM) coupled with the bus **609** for storing information and instructions for the central processor **601**, and a non-volatile memory **603** (e.g., read only memory or ROM) coupled with the bus **609** for storing static information and instructions for the processor **601**. Computer system **600** also includes a data storage device **604** (e.g., a magnetic or optical disk and disk drive) coupled with the bus **609** for storing information and instructions. With reference still to FIG. 9, system **600** of the present invention also includes an optional alphanumeric input device **606** including alphanumeric and function keys (e.g., a conventional keyboard). Alphanumeric input device **606** may be coupled to bus **609** for communicating information and command selections to central processor unit **601**. System **600** also optionally includes a cursor control device **607** (e.g., a conventional mouse) coupled to bus **609** for

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communicating user input information and command selections to central processor unit **601**. System **600** also includes an optional display device **605** (e.g., a conventional monitor) coupled to bus **609** for displaying information. One or more signal input/output communication devices **608** coupled to bus **609** may provide communication with external devices.

The present invention has particular advantage in integrated circuits having moderate to high logic complexity, such as microprocessors, digital signal processors, field programmable gate arrays (FPGAs), complex programmable logic devices (CPLDs), and speech recognition chips.

CONCLUSION/SUMMARY

15 Thus, the present invention provides a convenient, simple and efficient architecture, method and system for. The present method, system and architecture greatly, enabling one to, and improve.

The foregoing descriptions of specific embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the Claims appended hereto and their equivalents.

What is claimed is:

1. A method of placing and routing, comprising:
 - a) determining a boundary condition for signal paths between components at endpoints of said signal paths in a circuit, wherein each of said components receives a clock signal and a plurality of said signal paths comprise n wires and $(n-1)$ circuit elements in alternating serial communication between said components, n being an integer of 2 or more; and
 - b) using a computer or data processing system, placing said circuit elements and routing said wires between said components and said circuit elements such that no signal path in said circuit exceeds said boundary condition, wherein said boundary condition is based on (i) a period or frequency of said clock signal and (ii) a resistivity of said wires.
2. The method of claim 1, wherein said boundary condition comprises a maximum propagation time or a maximum length of said signal paths.
3. The method of claim 2, wherein said boundary condition comprises a maximum length of said signal paths.
4. The method of claim 1, further comprising the step of routing said clock signal to said components.
5. The method of claim 1, wherein said clock signal received by each of said components is the same clock signal or a logical equivalent thereof.
6. The method of claim 1, further comprising the step of placing said components, elements, and wires in a floor plan corresponding to said circuit.
7. The method of claim 6, wherein said components are placed in said floor plan such that no signal path in said circuit exceeds said boundary condition.
8. The method of claim 7, wherein placing said components in said floor plan comprises regularly spacing said

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components at first endpoints of said signal paths from a nearest component at a second endpoint of each of said signal paths in said floor plan.

9. The method of claim 6, wherein placing said components in said floor plan comprises regularly spacing at least a subset of said components at first endpoints of said signal paths from a nearest component at a second endpoint of each of said signal paths.

10. The method of claim 6, further comprising determining whether any of a plurality of signal paths exceeds said boundary condition, and if any of said signal paths exceeds said boundary condition, then:

- i) re-placing at least one of said elements and/or said components in a different location in said floor plan, and
- ii) re-routing said wires between said re-placed elements and/or components such that no signal path in said circuit exceeds said boundary condition.

11. The method of claim 10, wherein said determining comprises calculating said boundary condition from circuit parameters comprising (i) a period or frequency of said clock signal and (ii) a resistivity of said wire.

12. The method of claim 11, wherein said circuit parameters further comprise (iii) a characteristic resistivity or time delay associated with each circuit element.

13. The method of claim 1, wherein said circuit elements do not receive said clock signal.

14. The method of claim 13, further comprising the step of placing said components and said circuit elements in a floor plan corresponding to said circuit.

15. The method of claim 14, further comprising the step of routing said clock signal to said components.

16. The method of claim 15, wherein said clock signal received by each of said components is the same clock signal or a logical equivalent thereof.

17. The method of claim 1, wherein said boundary condition is further based on (iii) a characteristic resistivity or time delay associated with each circuit element.

18. The method of claim 1, wherein said determining comprises calculating said boundary condition from (i) said period or frequency of said clock signal and (ii) said resistivity of said wire.

19. The method of claim 1, wherein said boundary condition is determined empirically from input data.

20. The method of claim 1, wherein said components comprise a first component at a first endpoint and a second component at a second endpoint of each of said signal paths.

21. A non-transitory computer-readable medium comprising a computer-executable set of instructions, said instructions adapted to perform the steps of:

- a) calculating a boundary condition for all signal paths between components at endpoints of said signal paths in a circuit, wherein each of said components receives a timing signal in a common clock domain, a plurality of said signal paths independently comprise n wires and (n-1) circuit elements in alternating serial communication between said components, n being an integer of 2 or more, and said boundary condition is calculated from circuit parameters comprising (i) a period or frequency of said clock signal and (ii) a resistivity of said wires; and

- b) placing said circuit elements and routing said wires between said components such that no signal path in said circuit exceeds said boundary condition.

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22. The non-transitory computer-readable medium of claim 21, wherein said boundary condition comprises a maximum propagation time or a maximum length of said signal paths.

23. A non-transitory computer system comprising the computer-readable medium of claim 22, configured to execute said computer-executable set of instructions.

24. The non-transitory computer-readable medium of claim 21, further comprising the step of placing said components, elements, and wires in a floor plan corresponding to said circuit such that no signal path in said circuit exceeds said boundary condition.

25. The non-transitory computer-readable medium of claim 24, wherein placing said components in said floor plan comprises regularly spacing said components at first endpoints of said signal paths from a nearest component at a second endpoint of each of said signal paths in said floor plan.

26. The non-transitory computer-readable medium of claim 24, wherein said circuit elements are placed in said floor plan.

27. The non-transitory computer-readable medium of claim 24, further comprising determining whether any of a plurality of signal paths exceeds said boundary condition, and if any of said signal paths exceeds said boundary condition, then:

- i) re-placing at least one of said elements and/or said components in a different location in said floor plan, and
- ii) re-routing said wires between said re-placed elements and/or components such that no signal path in said circuit exceeds said boundary condition.

28. The non-transitory computer-readable medium of claim 27, wherein said determining comprises calculating said boundary condition from circuit parameters comprising (i) a period or frequency of said clock signal and (ii) a resistivity of said wire.

29. The non-transitory computer-readable medium of claim 28, wherein said circuit parameters further comprise (iii) a characteristic resistivity or time delay associated with each circuit element.

30. A non-transitory computer system comprising the computer-readable medium of claim 27, configured to execute said computer-executable set of instructions.

31. The non-transitory computer-readable medium of claim 21, further comprising the step of routing said clock signal to said components.

32. The non-transitory computer-readable medium of claim 31, wherein said clock signal received by each of said components is the same clock signal or a logical equivalent thereof.

33. The non-transitory computer-readable medium of claim 21, wherein said circuit parameters further comprise (iii) a characteristic resistivity or time delay associated with each circuit element.

34. A non-transitory computer system comprising the computer-readable medium of claim 21, configured to execute said computer-executable set of instructions.

35. The non-transitory computer-readable medium of claim 21, wherein said components comprise a first component at a first endpoint and a second component at a second endpoint of each of said signal paths.

36. The non-transitory computer-readable medium of claim 21, wherein said circuit elements do not receive said clock signal.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 7,823,112 B1
APPLICATION NO. : 10/449757
DATED : October 26, 2010
INVENTOR(S) : Mikhail Makarov et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, item (57),

IN THE ABSTRACT

Line 9 of the Abstract: change “comments” to --components--.

IN THE SPECIFICATION

Column 11, line 15: change “This” to --Thus--.

IN THE CLAIMS

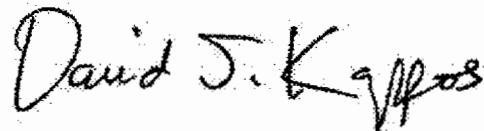
Column 12, Claim 3, line 54: change “a maximum length” to --said maximum length--.

Column 13, Claim 10, line 10: change “a plurality of signal paths” to --said plurality of signal paths--.

Column 13, Claim 18, line 40: change “said boundary condition” to --a boundary condition-- and
change “said period” to --a period--.

Column 14, Claim 27, line 22-23: change “a plurality of signal paths” to --said plurality of signal
paths--.

Signed and Sealed this
Twenty-sixth Day of April, 2011



David J. Kappos
Director of the United States Patent and Trademark Office